



COMPOSITES

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ABSTRACT

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This thesis was a literature study concerning composites. With composites becoming increasingly popular in various areas such as aerospace industry and construction, the research about composites has a significant meaning accordingly. This thesis was aim at introducing some basic information of polymer matrix composites including raw material, processing, testing, applications and recycling to make a rough understanding of this kind of material for readers.

Polymeric matrices, fillers, reinforcements, prepregs and coatings are discussed in raw materials and some detailed information about raw materials was involved also in this chapter. There were six common processing methods introduced in processing part and three aspects of test were described in test chapter.

Applications and recycling were covered in the last two chapters. Although composites, a kind of mixture, are difficult to be recycled, there were still some considerable solutions referred to.

Key words: composites raw materials processing testing application

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ABBREVIATIONS AND TERMS

ASTM	American Society for Testing and Materials
BC	Before Christ
CMCs	Ceramic Matrix Composites
CVD	Chemical Vapor Deposition
EMI	Electro Magnetic Interference
FRP	Fiber Reinforce Plastics
GF	Glass Fibers
GP	General Purpose
IITRI	Illinois Institute of Technology Research Institute
ISO	International Organization for Standardization
Kevlar	Trade name for Aramid fibers
MMCs	Metal Matrix Composites
NASA	the National Aeronautics and Space Administration
N_f	The fatigue life
PEEK	Polyether Ether Ketone
PMCs	Polymer Matrix Composites
RFI	Radio Frequency Interference
PPT	Power Point
RTM	Resin Transfer Molding
SAE	Society of Automotive Engineers
T_g	A glass transition temperature
TPs	Thermoset Polyesters
UPs	Unsaturated Polyesters
UPRS	Unsaturated Polyester Resins
UV	Ultraviolet
VE	Vinyl Ester

1 INTRODUCTION

1.1 Conception

Composite materials are a kind of material from two or more constituent materials with significantly different chemical and physical properties. Composite material is a mixture. They play an important role in many areas. It have another name called composition materials or shortened to composites.

Composite materials have many differences compared with metals. Each material be contained in composite material can produce a synergistic effect, so that the overall properties is better than the original material. In other words, the individual constituents in composite materials retain their separate properties and do not dissolve or merge together. These separate material acts together to form the necessary stiffness or mechanical strength. (Wikipedia 2014, web) The new material may be preferred because the materials are stronger, lighter or less expensive comparing with traditional materials. Composite materials meet various requirements so that they have a very good future.

At present, this definition usually means the composite in which fiber as reinforcement in a resin matrix. (Armstrong, K., Bevan, L., Graham, C. & William, F 2005, 1)

Reinforced composites include the resin and high-strength reinforcement such as glass, carbon etc. The fiber in composites may be in a fixed format, oriented or random. (Kutz & Myer 2011, 203) The fiber stands for the reinforcement and the resin stands for the matrixes in composites.

The matrix plays a role to give shape which is especially useful to the whole structure in composite because that they can be shaped easily. The matrix covers and surrounded the reinforcements so that it can contact the environment directly. Another good thing is the matrix can protect the reinforcement from environment. Besides, it can transfer the load from environment as well as contribute to properties. In terms with the reinforcements, it can offer the composite some good properties. Table 1 shows roles of the matrix and reinforcement in a composite. (Strong, A. & Brent 2008, 4)

TABLE 1 Roles of the matrix and reinforcement in a composite (Strong, A & Brent, 2008, 5)

Matrix	Reinforcements
<ul style="list-style-type: none"> • Gives shape to the composite part • Protects the reinforcements from the environment • Transfers loads to the reinforcements • Contributes to properties that depend upon both the matrix and the reinforcements, such as toughness 	<ul style="list-style-type: none"> • Give strength, stiffness, and other mechanical properties to the composite • Dominate other properties such as the coefficient of thermal expansion, conductivity, and thermal transport

1.2 Categories

According to the structure of composites, the composite can be divided into fiber reinforced composites, sandwich composites, fine particles containing composites and hybrid composites. According to the basis of the nature of matrices, they can be mainly divided into polymer matrix composites (PMCs), ceramic matrix composites (CMCs), metal matrix composites (MMCs) and carbon matrix composites (or carbon carbon composites).

In this text, the polymer matrix composites are the main materials to be explained. According to Mallick, P. (2010, 17), PMCs are produced by combining high modulus fibers and high strength with either a thermoplastic or a thermoset polymer matrix. The fibers used with most polymer matrix composites are glass, carbon or Kevlar fibers. (Mallick, P. 2010, 17) Compared with ceramic matrix composites and metal matrix composites, PMCs need a much higher temperature to process. The use of polymer matrix composites, especially fiber reinforced composites has increased in the last three decades. On the other hand, PMCs can reduce fuel consumption and increase range of applications because of the high specific strength and stiffness.

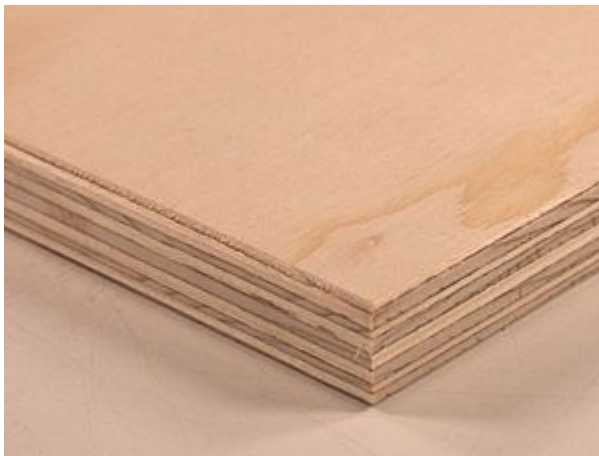
1.3 History

Straw and mud mixed together to produce bricks for building construction were the earliest man-made composite materials. African “mud” huts became stronger if it contains grasses and sticks. Egyptian tomb painting recorded the ancient brick-making. According to the ancient time, it was known that the bricks have better strength property if

filled with chopped straw. One of the oldest man-made composite materials is wattle and daub. It was found about 6000 years ago. Another composite material, concrete, is used more than all other man-made materials around the world. About 7.5 billion cubic meters of concrete were made per year before 2006, which means everyone on earth can use more than one cubic meter. A kind of paper, papyrus, has a visible fibrous reinforcement.

Woody plants are a kind of yield natural composites which were used by mankind, as well as in the construction and scaffolding. Some examples about this kind of natural composites are the true wood from trees and such plants like palms and bamboo.

Plywood is a kind of composite which was found in 3400 BC in Ancient Mesopotamians. There are gluing wood at different angles, which can let the natural wood have better properties.



PICTURE 1 Softwood plywood made from spruce (Wikipedia 2014,web)

In 2181-2055 BC, it was found that cartonnage layers of linen or papyrus soaked in plaster dates to the First Intermediate Period of Egypt. And it was used for death masks.



PICTURE 2 A fragment of cartonnage (Wikipedia 2014)



PICTURE 3 Death mask of Samuel F.B. Morse (Wikipedia 2014)

After that, the cob material (mud bricks or mud walls) have been used for thousands of years. The picture 4 indicates a modern cob house near Ottery St Mary in the United Kingdom. A book written around 25 BC recorded the concrete.



PICTURE 4 A modern cob house near Ottery St Mary in the United Kingdom (Wikipedia 2014)

Papier-mâché has been used for hundreds of years. It is a composite of paper and glue. The picture 5 shows the Papier-mâché mask created with the pulp method. In 1907, the first artificial fiber reinforced plastic was used.



PICTURE 5 Papier-mâché mask created with the pulp method (Wikipedia 2014)

1.4 Advantages and disadvantages

Fiber-reinforced composite materials give the composite the mixture of better strength and modulus compared with the many traditional metallic materials. Fiber-reinforced composite have many advantages. For example, they have low specific gravities, good modulus-weight ratios and good the strength-weight ratios.

However, composites also have many disadvantages, such as the lack of well-defined design rules, the costs of the materials and so on. Besides, difficulty in recycling of materials is a problem. Table 2 indicates the advantage and disadvantages of composites.

TABLE 2 Advantage and disadvantages of composite (Strong, A & Brent 2008, 2)

Advantages	Disadvantages
<ul style="list-style-type: none"> • Lightweight • High specific stiffness • High specific strength • Tailored properties (anisotropic) • Easily moldable to complex (net) shapes • Part consolidation leading to lower overall system cost • Easily bondable • Good fatigue resistance • Good damping • Crash worthiness • Internal energy storage and release • Low thermal expansion • Low electrical conductivity • Stealth (low radar visibility) • Thermal transport (carbon fiber only) 	<ul style="list-style-type: none"> • Cost of materials • Lack of well-proven design rules • Metal and composite designs are seldom directly interchangeable • Long development time • Manufacturing difficulties (manual, slow, environmentally problematic, poor reliability) • Fasteners • Low ductility (joints inefficient, stress risers more critical than in metals) • Solvent/moisture attack • Temperature limits • Damage susceptibility • Hidden damage • EMI shielding sometimes required

2 RAW MATERIAL

2.1 Polymeric matrices

The matrix phase of commercial polymeric composites can be classified as either thermoset or thermoplastic.

Thermosetting resins include polyesters, vinyl esters, epoxies, bismaleimides, and polyamides. Thermoplastic resins, sometimes called engineering plastics, include some polyesters, polyether imide, polyamide imide, polyphenylene sulfide, polyether ether ketone (PEEK) and liquid crystal polymers. (U.S. Congress 1988, 76)

Properties of different polymers will determine the application to which it is appropriate. The main advantages of polymers as matrix are low cost, easy to process, good chemical resistance and low specific gravity. On the other hand, low strength, low modulus and low operating temperatures limit their use. Varieties of polymers for composites are thermoplastic polymers, thermosetting polymers, elastomers, and their blends (Sabu Thomas et al. 2012, 7)

TABLE 3 Some properties of resin (U.S. Congress 1988, 76)

Resin type	Process temperature	Process time	Use temperature	Solvent resistance	Toughness
Thermoset	Low	High	High	High	Low
Toughened thermoset	↑	↓	↑	↑	↓
Lightly crosslinked thermoplastic.	High	Low	Low	Low	High
Thermoplastic.					

*Use temperature means high temperature resistance

The matrix isolates the fibers from one another in order to prevent abrasion and formation of new surface flaws and acts as a bridge to hold the fibers in place. A good matrix should possess ability to deform easily under applied load, transfer the load onto the fibers and evenly distributive stress concentration. (Chitta, R. 2010, 8)

2.1.1 Polyester resins

Polyesters are used extensively in commercial applications. Relatively cheap with processing flexibility, they are used for continuous and discontinuous composites. (Campbell, F. 2006, 280)

The basic chemical structure of typical polyester (Figure 1) contains ester groups and one unsaturated or double-bond reactive groups ($C = C$). Polyesters are formed by the condensation polymerization of a diacid and a dialcohol (a diacid means two organic acid groups are present in a molecule and a dialcohol, sometimes called a diol, has two alcohol groups in the molecule) (Hoa & Suong V. 2009, 50)

Polyesters are usually viscous liquids consisting of a solution of polyester in a monomer, usually styrene. The formation of the cross-linked polyester network with styrene is shown schematically in figure 2. A solution of polyester and styrene alone polymerizes too slowly for practical purposes. Therefore, small amounts of accelerators or catalysts are always added to speed up the reaction. Catalysts are added to the resin just prior to use, to initiate the polymerization reaction. The catalyst does not actually take part in the chemical reaction, but simply activates the process.

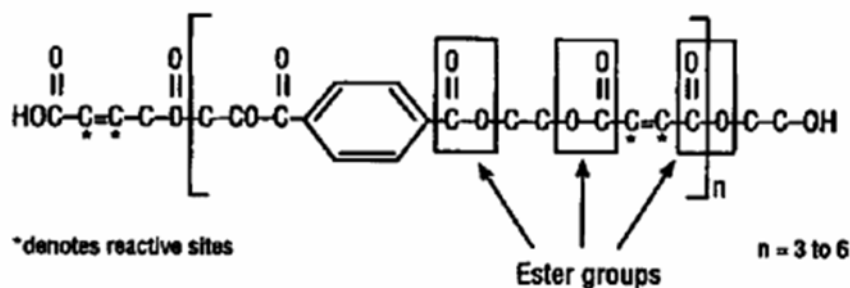


FIGURE 1 The molecule structure of polyester resins (Campbell, F. 2004, 66)

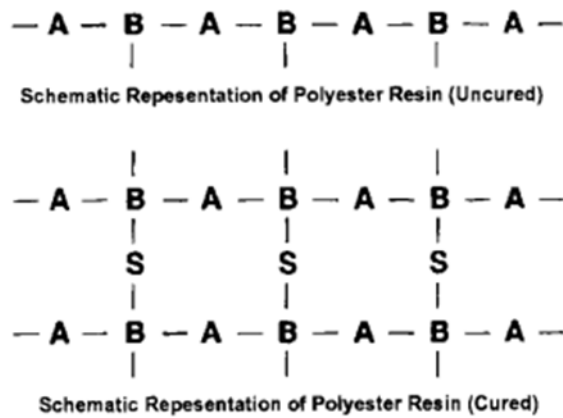


FIGURE 2 The formation of the cross-linked polyester network with styrene (Campbell, F. 2004, 67)

Polyesters are used extensively in commercial applications but are limited in use for high performance composites. Although of a lower cost than epoxies, they generally have lower temperature capability, lower mechanical properties, inferior weathering resistance and exhibit more shrinkage during cure. Polyesters have been used mainly with glass fibers (normally E glass) to make many commercial products such as pipes, boats, corrosion resistant equipment, automotive components, and fiber reinforced rods for concrete reinforcement. (Campbell, F. 2004, 66)

Unsaturated Polyester resins (UPRs) have been widely used as matrices for composite materials since their development in the 1940s. Their leading industrial position among thermosets for such purposes arises from several factors. They offer equilibrium in mechanical properties along with a low cost, in addition to a high processing versatility. (N/A 1997, 1)

Unsaturated polyesters (UP) or, alternately and equivalently, thermoset polyesters (TPs) are, by far, the most commonly used thermosetting resins for composites. They are used in applications such as boats, corrugated sheet and golf cars. This wide-spread application is due to many factors, not the least of which is low cost. Unsaturated polyesters are commonly priced about 25 % less than vinyl esters and about 33–50 % less than epoxies. In addition to their cost advantage, poly-ester thermosets have advantages in ease of cure, ease of molding, a wide range of property possibilities, and a wide experience base in developing technologies and design parameters. However, polyester thermosets have several drawbacks or disadvantages in properties and manufacturing such as relatively

poor durability, brittleness and air pollution difficulties. In general, however, the advantages seem to outweigh the disadvantages and polyesters continue to be the resins of first choice for many composite products. (Strong, A & Brent 2008, 47)

2.1.2 Epoxy resins

The bulk of epoxy resins are still those based on epichlorohydrin and dihydroxy-diphenyl propane and may be represented by the following structure and Table 4 shows some physical properties of epoxy resins.

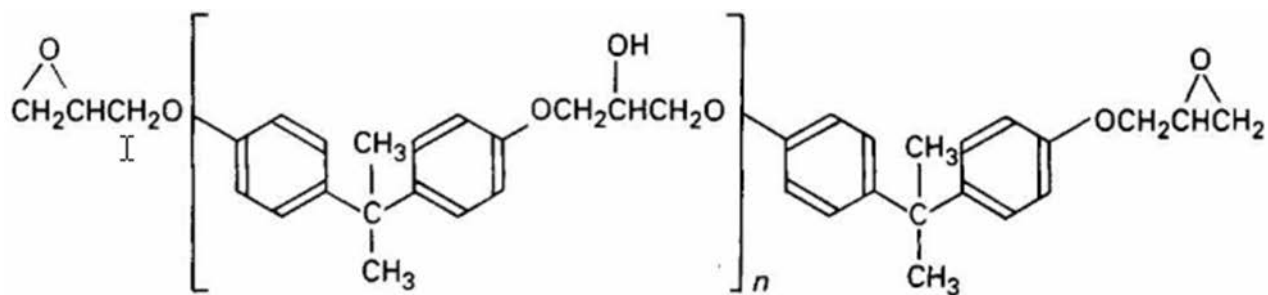


FIGURE 3 The molecule structure of epoxy resins (Shreir, L., Jarman, R. & Burstein, G. 1994. 14:110)

TABLE 4 Some physical properties of epoxy resins (Mark & James E. 2009, 138-140)

property	Units	condition	Value	Reference
Specific gravity	-	General	1.01-2.00	(138-140)
Impact strength, Izod	Jm ⁻¹	General	0.345-53.7	(138-140)
Hardness	Rockwell	General	109-118	(138-140)
Tensile strength at break	MPa	General	0.00621-69.8	(138-140)
Elongation at break	%	General	0.40-7.9	(138-140)

There are three types about epoxy resins.

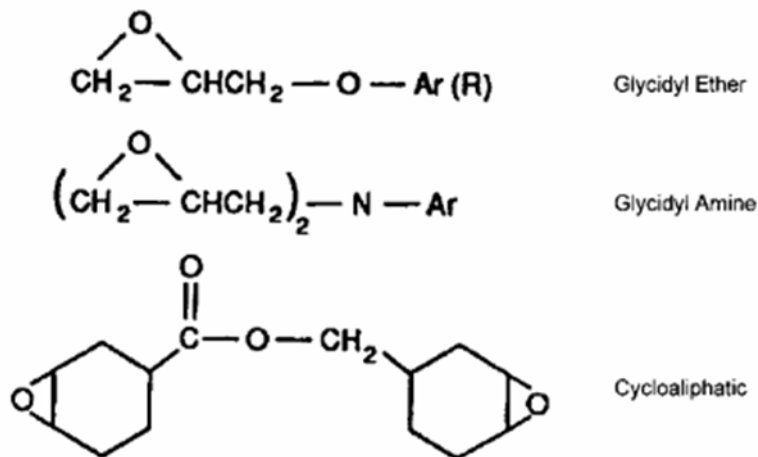


FIGURE 4 Three types about epoxy resin (Campbell, F. 2006, 68)

Epoxy resins traditionally are made by reacting epichlorohydrin with bisphenol A, which are linear polymers that cross-link, forming thermosetting resins basically by the reaction with amine-type compounds. (Campbell, F. 2004, 40) However, they have long curing times and poor mold release characteristics.

Comparing with polyester resins, they have excellent chemical resistance, low water absorption property and low cure shrinkage.

In composites, there are some advantages by using an epoxy matrix:

- (a) A wide variety of properties
- (b) Low shrinkage during cure, lowest within other thermosets,
- (c) Good resistance to most chemicals,
- (d) Good adhesion to most fibers, fillers,
- (e) Good resistance to creep and fatigue,
- (f) Good electrical properties.

With following principal disadvantages:

- (a) Sensitivity to moisture (after moisture absorption (1-6%), there is usually a decrease in the following: heat distortion point, dimensions and physical properties)

- (b) Difficulty in combining toughness and high temperature resistances, as explained previously,
- (c) Susceptibility to UV degradation
- (d) Cost - epoxies are more expensive than polyesters (Akovali, G. 2005, 219-220)

Epoxy resins can be used as a matrix for making high-strength composites with glass, carbon and Kevlar[®] fibers (an aromatic polyamide fiber) because they are chemically compatible with most substrates and tend to wet surfaces very easily. Such composites are exclusively used for aerospace applications. The aerospace industries are dominated by epoxy resins due to the excellent process ability and useful properties of network polymers. This is because epoxy composites can satisfy the technical requirements of structural material for civil and military aerospace applications, namely flooring panels, ducts, wings and vertical and horizontal stabilizers. Such composites are also used to produce lightweight vehicle frames, racing cars, musical instruments, and industrial components with high strength to weight ratio. (Ratna, D. 2009, 180)

The major use of epoxy resins is in the electronics industry. They are extensively used in motors, generators, transformers, switchgears, bushings, and insulators. Epoxy resins are excellent electrical insulators and protect electrical components from short circuiting, dust and moisture. In the electronics industry, epoxy resins are the primary resin used in molding integrated circuits, transistors and hybrid circuits and in making printed circuit boards. (Ratna, D. 2009, 180)

2.1.3 Vinyl ester resins

Vinyl esters (Figure 5) are very similar to polyesters but have only reactive groups at the end of the molecular chain. Since this result in lower cross-link densities, vinyl esters are normally tougher than the more highly cross-linked polyesters. In addition, since the ester group is susceptible to hydrolysis by water and vinyl esters have fewer ester groups than polyesters, they are more resistant to degradation from water and moisture. (Campbell, F. 2006, 67)

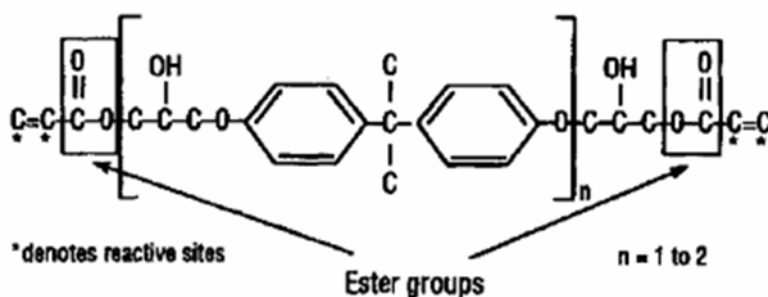


FIGURE 5 The molecule structure of vinyl ester resins

Vinyl ester resins are thermosetting resins that consist of a polymer backbone R' with a reactive termination. The general formula for the vinyl ester resin is shown in Figure 6. (Hoa & Suong V. 2009, 85)

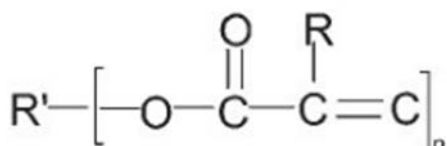


FIGURE 6 The general formula for the vinyl ester resin (Baker et al. 2004, 101)

In Figure 6, R' represents the rest of the molecule and R represents either the atom H (for acrylate vinyl ester) or CH_3 (for methacrylate vinyl ester). Vinyl ester resins have intermediate properties between polyester resins and epoxies. The cost of vinyl ester resins is also intermediate between the cost of polyesters and epoxies. (Baker et al. 2004, 101)

Physical properties are in general very similar to those of the polyesters. Formulations varieties of the vinyl esters have been developed so that these are capable of operating at relatively high temperatures and available in addition to fire-retardant grades. (Cheremisinoff, N.P. 1995, 48)

The major advantages of vinyl esters are

- a) They can combine the chemical resistance of epoxies with the easy processing of polyesters;

- b) reactive double bonds only on the end of the polymer chains and their high relative reactivity with styrene result in a lower cross-link density and better mechanical properties in the cured polymer;
- c) Improved bond strength between the fiber and matrix exists.

The major disadvantages of vinyl esters include

- a) Their higher costs when compared to polyesters
- b) Higher shrinkage levels than epoxy resins. (Baker et al. 2004, 101)

Vinyl ester resins have good mechanical property and can be fabricated with the same processes as used with conventional polyesters. Recent reviews show that they are becoming very important in new industrial applications such as coatings, printed circuit boards, metal foil laminates, building materials, ship building, automotive parts and fiber reinforced composites. Such developments are not only due to the good chemical properties of the cured resins but also to the opportunities offered to the fabricator to combine the mechanical properties of epoxies with the easy processing in use of unsaturated polyesters. Furthermore, their low molecular weight in comparison with that of unsaturated polyesters allow them to incorporate a high ratio of fillers (60 to 70 % by weight) and also good wetting of fibers (Kulshreshtha, A.K.& Vasile,C. 2002, 365)

Specifically, vinyl ester resins have good corrosion resistance. Applications include use in tanks, piping and ducts primarily for handling dilute acids, solvents and fuels, corrosion-resistant mixing vessels, precipitation vessels, scrubbers and process columns. In electrical industries, VE resin-based FRP are used to make components for electricity generating stations, transmission and distribution, televisions, and antennas. They are also used for making electrical maintenance equipment such as ladders and booms. Better water resistance makes them suitable for use in air conditioners, humidifiers and other household appliances. Vinyl ester resins perform better in underwater applications than epoxy resins. Thus VE resins are extensively used for marine applications. Examples are hull construction of various types of sail and motor boats, fishing boats and naval vessels. (Baker et al. 2004, 102)

2.1.4 Phenolic resins

Phenolic resins are produced by a polycondensation reaction between of phenol or phenol derivative and formaldehyde .this process will use an acid or base catalyst. The quality and type of product are determined by the type of catalyst and the ratio of the reactants. When the reaction is produced beyond the gel point, it will produce a three-dimensional matrix but what we used is produce just before the gel point. Resoles and Novolacs are the main types.

Phenolic resins have a lot properties such as a good resistance to chemicals especially acids, good mechanical strength, good electrical properties and excellent thermal resistance , flame resistance, low smoke generation, none toxicity and high temperature resistance are typical characteristics of these resins . Because of its aromatic structure, phenolic resin offers flame- and smoke-resistance. Smoke density (ASTM E662) of phenolic resin is 16 compared with 480-515 for epoxy and 530 for vinyl ester. The cured resins exhibit a glass transition temperature (T_g) of $>150^{\circ}\text{C}$. Phenolic resins are widely used as molding compounds (Ratna D. 2009, 70) In addition, compared with the polyesters, phenolic are much cheaper and have higher temperature endpoints. That means phenolic resins retain a higher fraction of their original strength after long-term exposure to high temperatures. When properly formulated, their flame resistance surpasses the polyesters. (Cheremisinoff, N.P. & Cheremisinoff, P.N. 1995, 44)

Phenolic resins (and thermosets in general) are brittle without fillers. It is customary to use fillers and other additives to achieve their desired properties and characteristics. Hence, formulation is the essence. Table 5 presents the typical properties of different forms of phenolic resins, the effect of fillers on phenolic resin properties can be seen in Table 5. For example, the compressive strength of unfilled phenolic molding resin is about 10000 to 30000 psi compared to 26000 to 70000 psi for glass-filled phenolic molding resins.

TABLE 5 Phenolic resin properties (Goodman & S.H. 1998, 34-35)

Properties	Casting Resin Unfilled	Molding Resin Unfilled	Molding Resin Cellulose Filled	Molding Resin Woodflour Filled	Molding Resin Glass Fiber Filled
Tensile strength (at break) (psi)	5,000-9,000	7,000-8,000	5,000-9,000	5,000-9,000	7,000-18,000
Impact strength izod (notched) (ft-lb/in.)	0.24-0.4	0.2-0.36	0.2-0.6	0.24-0.6	0.5-18
Compressive strength (at rupture) (psi)	12,000-15,000	10,000-30,000	22,000-31,000	25,000-31,000	26,000-70,000
Flexural strength (at yield) (psi)	11,000-17,000	11,000-14,000	7,000-14,000	7,000-14,000	15,000-60,000
Elongation (at break) (%)	1.5-2.0	-----	0.4-0.8	0.4-0.8	0.1-0.2
Hardness (Rockwell)	M93-120	M124-128	E64-95	M100-115	E54-101
Heat deflection temperature (at 264 psi) (°F)	165-175	-----	300-350	300-370	350-600

Properties	Casting Resin Unfilled	Molding Resin Unfilled	Molding Resin Cellulose Filled	Molding Resin Woodflour Filled	Molding Resin Glass Fiber Filled
Coefficient of linear thermal expansion 10^{-4} (in./in. °C)	1,700-1,800	640-1,520	30-45	30-45	8-21
Thermal conductivity 10^{-4} (cal/sec cm °C)	3-5	-----	-----	4-8	8-14
Linear mold shrinkage (in./in.)	0-0.01	0-0.01	0.004-0.006	0.004-0.009	0.001-0.004
Dielectric strength (V/mm)	250-400	200-350	300-380	260-400	140-400
Dissipation factor (at 60 Hz) (* = 1 KHz)	0.10-0.15	0.06-0.10	* 0.04-0.20	0.03-0.3	0.01-0.1
Water absorption (24 H) (%)	0.2-0.4	0.1-0.2	0.05-0.9	0.3-1.5	0.03-1.2
Specific gravity	1.236-1.320	1.25-1.30	1.37-1.46	1.30-1.35	1.69-2.0

*Conversion factors: 1 psi = 0.006895 MPa

Phenolic resins need a high curing pressure, longer curing times and a short shelf life which is about 90 days when it exists in liquid stage .These are the drawbacks of this resins. In addition, plasticizers which are used to reduce the brittleness can incur a degradation of cured properties. Phenolic resins are typically opaque and range from pale amber and dark brown to black in color[16],the limited color range are regarded as another disadvantage.

Phenolic resins can be used into numerous areas. Currently, rubber compounding, tackifying applications and structural composites are the main aspects.

American Cyanamid Company produces modified, toughened phenolic resins for glass fiber, aramid fiber (Kevlar[®], Nomex[®]) and graphite composites suitable for aircraft interior and ablative applications. American Cyanamid's modified phenolic resin suitable for nylon and aramid composite helmets has high toughness and ballistic impact resistance. (Goodman & S.H. 1998, 59-60)

To enhance the properties of phenolic resins, some fillers and additives are needed. The fillers typically used with phenolic resins are: wood flour, cellulose, mineral fillers (asbestos, mica, and clay), silica, and graphite fiber.

(1) Silica is used for its abrasive, electrical and heat insulation properties, viscosity enhancement, and shrinkage and crack reduction. (Goodman & S.H. 1998, 39)

(2) Glass fiber (fiber glass). It has a composition of 55 % silica, 20 % Ca-, Mg- Oxides 14 % alumina, 10 % borates, and 1 % sodium and potassium oxides. It is used to improve impact strength, heat, and electrical insulation properties. (Goodman & S.H. 1998, 39)

2.2 Fillers

2.2.1 Definition

Filler is an inert mineral powder of rather high specific gravity (2.00-4.50) used in plastic products and rubber compounds to provide a certain degree of stiffness and hardness and to decrease cost. (Lewis & Richard J. 2007, 563) In the area of technology, filler is a material added to a polymer in order to reduce compound cost and/or to improve processing behavior and/or to modify product properties. (Wypych, G. 2010, 6)

Examples are calcium carbonate (whiting), barytes, blanc fixe, silicates, glass spheres and bubbles, slate flour, soft clays etc. Fillers have not coloring properties and they are similar to extenders and diluents in their cost-reducing function. (Wypych, G. 2010, 5)

2.2.2 Properties

Fillers usually do not reduce the cost of material manufacturing and they are not inert materials added to fill space (if they are used in this way, they likely degrade properties of the material). Besides, fillers can be modified and tailored to any application and modify practically all properties of the material and influence the design, manufacture and use. Filler are highly influenced plastics performance and the performance of other materials. Fillers used in the plastics applications are increasing. (Wypych, G. 2010, 5)

TABLE 6 Different fillers and the properties (Packham, D. 2005, 414)

filler	reinforcing capability
Coal dust	none
Ground whiting (calcium carbonate)	none
Precipitated whiting (stearate coating)	slight
Calcium silicate	slight
clays	Semi-reinforcing
Aluminum silicate	Semi-reinforcing

Fillers have a tendency to increase resin viscosity. They are generally mixed into the resin with any pigments or catalysts. As a rule of thumb, no more than 40 of the entire mixture should be filler or properties will be reduced. The main justification for using fillers is that they reduce materials costs. However, if proper amounts are used, they can reduce curing shrinkage and improve surface appearance. Reducing shrinkage with the aid of fillers can also improve water resistance and weathering properties. (Cheremisinoff, N.P. 1995, 31)

The purpose of fillers is to enhance and or provide various properties to the plastics to which they are applied. They can reduce cost, provide body, minimize curing time, minimize shrinkage, improve thermal endurance, provide additional strength and mechanical properties and enhance electrical and chemical characteristics. Table 6 lists a number of different fillers and the properties they can provide to plastics. (Cheremisinoff, N.P. 1995, 31)

2.2.3 Classification

The fillers can be divided into two parts: reinforcing and non-reinforcing. Reinforcing fillers can be subdivided into two types, white and black. The black fillers mean carbon blacks. The white fillers mean silica, silicates and calcium carbonate. Black fillers are more important between them. The particle size ranges from 10 to 500 nm. In general, the ASTM D1765 will be used to divide by the size and surface. At an equivalent volume loading, reduction of particle size increases reinforcement, leading to higher tensile strength and modulus, increased abrasion and fatigue resistance and higher loss angle. The processing is also affected; mixing cycles being longer and the cure rate higher. Carbon blacks of smaller particle size are also more expensive. (Packham, D. 2005, 412)

The carbon black in the nature is very complicated. According to particle size, there are different grade in the nature, such as surface character (including surface area) and structure. The mechanisms of reinforcement are not fully understood, but it is likely that different levels of adhesion between filler and polymer play an important part. The Surface energy and structure will vary, not only between grades, but also between different parts of the same filler. Diverse chemical groups have been detected on the surfaces of carbon fillers: alcohol, phenol, quinone, lactone, carboxyl as well as free radicals. Thus, depending on the chemistry of the filler surface and of the polymer, different levels of adhesion associated with van der Waals forces or chemical bond may lead to different effects on the properties of the filled elastomer. Most carbon black is produced by the furnace method of burning oil in a controlled oxygen environment. The price therefore follows that of oil. (Packham, D. 2005, 412)

White reinforcement is obtained through the use of silica. Grades are defined by size surface area and method of manufacture, although there is no universally accepted grading system such as exists for carbon black. In general, unless one needs a non-black rubber, less trouble is experienced with black reinforcement. (Packham, D. 2005, 413)

The non-reinforcing white fillers, frequently used as extenders to reduce the cost of the final compound, do not greatly increase the levels of measured adhesion; these are generally inert materials and, whereas they reduce the elongation and therefore produce an

increase in the compound modulus, they do not reinforce the compound and do not significantly increase the tear strength. (Wootton, D. 2001, 117)

Non- or semi-reinforcing fillers are usually added to reduce cost. In natural rubber or polychloroprene, they may be used alone, but with non-crystallizing polymers such as butadiene acrylonitrile or styrene butadiene copolymers, they can only be used in conjunction with the reinforcing filler. Their effect is to reduce tensile strength and elongation, tear resistance and resistance to set. The effect on modulus varies according to choice of filler, but it is always much weaker than that of a reinforcing filler. The ranking of such fillers is imprecise because it depends upon the use that may be made of them. Certain clays perform well in insulation compounds and precipitated whiting are more than adequate to extend rubbers for components that are not subjected to high levels of stress. (Packham, D. 2005, 413)

2.2.4 Standards

Fillers must be selected first according to their ability to meet end-use requirements. These may be set out formally through specifications such as seen in SAE J200 or ASTM D 2000. Such specifications define tensile strength, hardness, age resistance, compression set and so on. The level of these requirements will be a good guide to filler types and grades. Tensile strengths higher than 14 MPa will certainly require reinforcing filler at a size of 50 nm or finer (N660) and for strength above 20 MPa, a particle size of 30 nm or less is recommended (N330). If dynamic properties are important, coarser fillers will give high resilience at equivalent levels of filler than will the finer grades. (Packham, D. 2005, 413-414)

Of equal importance to the properties of the molded component is the influence of the filler during the mixing and molding stages. Ease of incorporation in the rubber is important if a homogeneous mixture is to be produced. The more fine the filler, the more difficult it is to disperse. (Packham, D. 2005, 414)

Flow properties during molding influence the final quality of the component. High viscosity leads to poor flow procuring of the rubber and hence to weld lines, risk of early fatigue failure and poor-quality bonds. The finer the filler is, the higher the viscosity for any given volume of filler. The moisture content of any filler needs careful control. Ad-

verse levels of moisture ($>0.5\%$) will affect rubber cure rate, final modulus and bond strength. If these considerations be made are prior to the formulation of the compound, a high quality of rubber bonding can be achieved. (Packham, D. 2005, 414)

2.2.5 Common fillers

Calcium carbonate (CaCO_3) is the most common inexpensive plastics filler that is literally “filler” - its main value is to displace polymer in a product’s composition. It essentially reduces the amount of resin used in a product, which is especially useful when resin prices are high. Fine particles of CaCO_3 , loaded at 10-60%, can also increase a plastic’s stiffness, hardness, and dimensional stability. Environmentally, the mineral is naturally occurring (from limestone), chemically simple and commonly acceptable in food-contact packaging. And because it is simple, the relative amount of processing it undergoes in its production is low, even when compared with the relatively simple polyethylene resins it is commonly used in. Being a mineral, calcium carbonate does not degrade much from the heat of reprocessing as polymers do and it even lowers the processing energy of polyolefin conversion process. Thus it comes close to being an “environmental footprint- reducing” additive. (Tolinski, M. 2011, 119)

Talc and mica are simple, plentiful, inert and naturally occurring metal-hydrate silicate mineral fillers. They are used in engineering applications in polypropylene, adding properties to the low-cost polymer, such as increased modulus and heat-deflection temperature. The fillers’ mechanical-property effects are produced by their plate-like particles’ high aspect ratios (the ratio of a particle’s major dimension [length] to its minor dimension [thickness]). Talc in particular allows PP to compete in plastics applications that typically require more complex and more expensive engineering resins. Thus, talc and mica could be seen as green-enabling technologies. They allow reduced use of relatively complex engineering polymers such as nylon, while expanding the use of simpler ones like PP, which have less complicated chemical synthesis processes and better recycling potential. (Tolinski, M. 2011, 119)

Wollastonite is a less often used mineral filler with needle-like particles (which are not hazardous like asbestos). At 10-20% loadings, wollastonite can increase a polyolefin’s tensile and flexural strength, while offering higher dimensional stability and less mold shrinkage than talc or CaCO_3 , (Tolinski, M. 2011, 119) Wollastonite is a white mineral

that consists essentially of calcium metasilicate. It is commonly used as an inorganic filler material of thermoplastic polymers for molding. The wollastonite fibers are treated with silane surface treatments by using γ -aminopropyl-ethoxysilane γ -glycidoxypopyl methylsilane.(Fink, J. 2008, 404)

2.3 Reinforcement

The fibers offer composites some extra purposes to give adequate functional properties to the product, which like strength, stiffness and other mechanic properties.

2.3.1 Glass fibers

By melting, pultrusion, winding and further processing, Glass fiber is made from glass marble or recycled glass to a group of products consisting of many individual glass fibers (filament). Glass is relatively inexpensive, so it commonly used in fiber form as an reinforcement material in composites.

Glass fiber can be used in a lot of fields especially for the production of large composite structures due to the following advantages. Compared with other materials, the price of glass fiber attracts more attention of manufactures when making the large composites like boats, sports equipment, because the glass fiber will save money, providing a high strong strength and light weight at a same time. Furthermore, glass fiber is one of inorganic fibers which will not cause burning itself and thermal conductivity of it is very low, so glass fiber has a high temperature resistance. Another property is chemical resistance. Glass fiber is good at avoiding corrosion from acid, alkali and some solvents. Additionally, glass fiber is electrically insulating and has moisture resistance and high tensile strength.

However, glass fiber also has some disadvantages: the material is not very stiff and has poor wear resistance, flexibility and bend resistant.

Glass fiber has different variants. They are E-glass, C-glass, S-glass, A-glass, D-glass, R-glass, ECR-glass etc.

The chemical compositions of different glass fibers can be seen from Table 7.

Table 7 Chemical compositions of glasses for fibers (Aravin Prince Periyasamy, PPT, 7, modified)

<i>Composition in wt% (typical values)</i>								
Oxide	E-Glass	C-Glass	S-Glass	A-Glass	D-Glass	R-Glass	ECR-Glass	Basalt
SiO ₂	55.0	66.0	65.0	67.5	74.0	60.0	61.0	52.0
Al ₂ O ₃	14.0	4.0	25.0	3.5	---	24.0	13.0	17.2
TiO ₂	0.2	---	---	---	---	---	---	1.0
B ₂ O ₃	7.0	5.0	---	1.5	22.5	---	---	---
CaO	22.0	14.0	---	6.5	---	9.0	22.0	8.6
MgO	1.0	3.0	10.0	4.5	---	6.0	3.0	5.2
Na ₂ O	0.5	7.5	---	13.5	1.5	0.5	---	5.0
K ₂ O	0.3	0.5	---	3.0	2.0	0.1	0.5	1.0
Fe ₂ O ₃	---	---	---	---	---	---	---	5.0
Softening Point	840°C	750°C	950°C	700°C	720°C	950°C	840°C	---

E-glass

E-glass almost dominates in the whole glass fiber market. The reason why it is so popular is due to the fact that E-glass has low electrical conductivity and lowest price.

Continuous and chopped E-glass is widely used in product manufacture. Its advantages are relatively low cost combined with high tensile strength and modulus, with individual filament strengths around 3500 MPa and modulus around 80GPa. Elongation-to-break is nearly 5%. (SMITHERS RAPRA, Reinforcement types, 2014)

ECR-glass

ECR-glass is good at resisting acid and alkali exposure. Their mechanical properties are similar to E-glass but they have less weight loss based on sulphuric acid exposure. (SMITHERS RAPRA, Reinforcement types, 2014)

A-glass

Soda lime silicate glasses known as high-alkali glass, because of poor water resistance, it rarely used in the production of glass fibers.

C-glass

Calcium borosilicate glasses which are characterized by the chemical resistance particularly acid resistance, but the poor electrical properties, mechanical strength is lower than E-glass fiber 10% to 20%.

D-glass

Borosilicate glasses used to produce dielectric glass fibers.

S-glass

S-glass is similar in its properties with E-glass, but it is 10-15% stronger than E-glass and heat resistance is better than that of E-glass. When the composite require high strength, modulus and high temperatures, S-glass is a better choice.

R-glass

Calcium aluminosilicate glasses which can add strength and acid corrosion resistance for composites

2.3.2 Carbon fibers

Carbon fibers refer to fibers which are at least 92 wt.% carbon in composition (Chung & Deborah D.L. 1994,3) and when the amount of carbon accounts over 99 % ,it is called a graphite fiber .They are manufactured from pitch fibers, polymer fibers or carbonaceous gases and they can be existed in short or continuous forms. Generally speaking, using carbonaceous to make carbon fibers is just in the short form while the others are made into two forms.

Compared with glass fibers (GF), the Young's modulus of carbon fibers is 3 times higher than GF, which means carbon fiber can have little elastic deformation when they are under a certain stress. Moreover, the most advantages is its thermal expansion is basically zero, which means carbon fiber can remain its basic form when heating, Another good property the carbon fibers have in high temperature is that if it manufactured properly, fatigue issues will not happen in carbon fiber composite. The carbon fibers can also be used to produce a lightweight structure with high stiffness and strength because their high stiffness to weight ratio and high strength property. Finally, carbon fiber is permeable to X-ray and does not corrode.

On the other hand, all materials have their own disadvantages. For instance, carbon fiber can be oxygenated under a strong acid atmosphere, metal carbide, carburizing and electrochemical corrosion will occur when it is combined with metal (such as aluminum), so it is better to do some surface treatments before this combination. Moreover, some special occasion should consider that carbon fiber is an electric conductor which will reflect radio waves.

In table 8, the classification of carbon fiber and their characteristics can be see

TABLE 8 Classification of carbon fibers based on their precursors and their characteristics (Somiya & Shigeyuki 2013, 44)

Precursor	Carbon fibers	Characteristics
Polyacrylonitrile (PAN)	PAN-based carbon fibers	Different grades and types
Isotropic pitch	Isotropic-pitch-based carbon fibers	General purpose grade Random cross-sectional nanotexture
Mesophase pitch	Mesophase-pitch-based carbon fibers	High modulus types Various cross-sectional nanotextures
Cellulose	Cellulose-based carbon fibers	General purpose grade Random nanotexture
Phenol	Phenol-based carbon fibers	General purpose grade Random nanotexture
Hydrocarbon gases	Vapor-grown carbon fibers	High graphitizability Annual-ring texture in cross-section

2.3.3 Boron fibers

Boron fiber is a kind of high-strength, high-modulus structural fiber made by depositing boron from vapor phase on white-hot tungsten filament.

Boron fibers are manufactured by chemical vapor deposition (CVD) of boron onto a heated substrate (either a tungsten wire or a carbon monofilament). Boron vapor produced by the reaction of boron chloride with hydrogen: (Kulshreshtha, A. & Vasile, C. 2002, 68)



There are three types of boron fiber industrially manufactured. They are boron fiber, boron carbide fiber and boron nitride fiber.

I Boron fibers: vapor-deposited filaments made by depositing vapor phase boron from a boron halogen compound on a heated tungsten wire. Tensile strength 100–200 cN/tex, E modulus 370–450 kN/mm². They are often used in aircraft and space application and it have a good future in these areas, like rotors, turbines, etc. (Rouette & Hans-karl 2001, 59)

II Boron carbide fibers: manufactured by the reaction of boron chloride and hydrogen with carbon fiber at high temperatures whereby a layer of B₄C is formed immediately on the carbon surface (conversion of approx. 50 % of the carbon to B₄C). Tensile strength 80 cN/tex, E modulus 340 kN/mm², stable to temperatures up to 2200 °C, high conductivity. They can be used to do protective clothing against radiation, heat insulation, etc. (Rouette & Hans-karl 2001, 59)

III Boron nitride fibers : Tensile strength approx.100 cN/tex, E modulus 28–90 kN/mm²; short-term temperature resistance up to 3000 °C; better corrosion resistance than carbon or glass fibers, high electrical resistance. Boron nitride fibers have been made into composites with a boron nitride matrix for use in electrical and electronic applications requiring a material that acts as both an electrical insulator and a thermal conductor.⁴ (Lee, stuart M 1992, 227) They can be used in aircraft and space applications; heat and electrical insulation; protective clothing against atomic heat flows, etc. (Rouette & Hans-karl 2001, 59)

Boron fibers have an extremely high tensile modulus: 379-414 GPa and with their relatively large diameter, they offer excellent resistance to buckling, which in its turn contributes to high compressive strength for composites. (Kulshreshtha, A. & Vasile, C. 2002, 68)

The main disadvantage of boron is its high cost, which is even higher than that of many forms of carbon fibers. For this reason, its use is at present restricted to aerospace applications (Murphy, J. 2008, 49)

2.3.4 Ceramic fibers

Ceramic fiber is a kind of fiber composed of ceramic material, and it usually used for reinforcement.

Developments in engineering technologies, especially in the aerospace and nuclear reactor industries, have required materials of high strength, whose stability in air is maintained at temperatures up to 600-700 °C, and even up to 1000 °C or higher. Ceramic fibers very largely meet these strict requirements and have found wide use as reinforcements in metal and ceramic matrix composite materials. (Mather, R. & Wardman, R. 2011, 230)

As with mineral wools, there are different types of ceramic fiber, but they are all made from a combination of alumina, silica and china clay and may be made by blowing or extruding the liquid melt. The most common ceramic fibers are silicon carbide and alumina (aluminum oxide) fiber. (Mobley, R. & Keith 2001, 144)

TABLE 9 Some properties of ceramic fibers (Mather, R. & Wardman, R. 2011, 231)

	<i>Silicon carbide (chemical vapour deposition)</i>	<i>Silicon carbide (spun)</i>	<i>Alumina</i>
Specific gravity	3–3.1	2.4–2.8	3.6–3.9
Tenacity (cN tex ⁻¹)	80–100	70–120	30–50
Elongation to break (%)	0.6–0.8	1.0–1.5	0.3–0.5

Two standard commercial processes are utilized for producing ceramic fibers: chemical vapor deposition and spinning. In chemical vapor deposition, the ceramic is deposited onto a heated tungsten or carbon filament, through the introduction of a gas, or gas mixture, containing silicon atoms. In the spinning technique, a precursor polymer is spun into filaments, whereupon the filaments are heated in order to convert them to ceramic fibers. (Mather, R. & Wardman, R. 2011, 230)

Silicon carbide monofilaments of diameter 40.1 mm can be produced by chemical vapor deposition onto a tungsten or carbon filament. Alumina fibers are produced by solution spinning and subsequent heat treatment. (Mather, R. & Wardman, R. 2011, 231)

Typical ceramic fibers are used at temperatures up to 1600 °C but their melting point can be in excess of 2000°C. (Mobley, R. Keith 2001, 144) Due to their outstanding resistance to very high temperatures, ceramic fiber is primarily used in materials that are required to withstand these temperatures. Applications of these materials include gas turbines in aircraft, the walls of nuclear reactors and heat exchangers. Fabrics made from ceramic fibers are used for the filtration of gases at high temperatures. (Mather, R. & Wardman, R. 2011, 232)

2.3.5 Steel fibers

The steel fiber is a kind of fiber manufactured by some methods including cutting off thin wire method, cold-rolled strip steel cutting and so on and the ratio of fiber length to diameter is from 30 to 100.

In composites, the steel fibers are generally divided into two parts. The first part includes steel cord, steel mesh and steel wire. The fibers in the second part are generally used in concrete.

Steel fibers are stronger than the fiber reinforcements, having excellent heat resistance, fatigue resistance and so on. Steel mesh or wires are also used in some glass and plastic production (Akovali, G. 2012, 149) and steel cord is used to reinforce rubber-made materials, like conveyor belts, radial tires and hoses.

Steel wire can be manufactured by a series of hot- and cold-working methods. Round steel fibers are manufactured by cutting or chopping the wire, typically having diameters in the 0.25-0.76 mm range. Flat sheet fibers having typical cross sections 0.15-0.41 mm thick and 0.25-0.90 mm wide are produced by shearing sheets. Fibers also have been produced from hot-melt extract. Deformed fibers, which are loosely bonded with the water-soluble glue in the form of a bundle, are also available. (Lee & Stuart M. 1992, 170)

Using steel cord in rubber can obtain very high strength with low extension and good flexibility. Some properties of steel fiber are shown in TABLE 10.

(Lee & Stuart M. 1992, 170)

TABLE 10 Some properties of steel fiber (Akovali, G. 2012,123, modified)

type of fiber	density g/cc	Tenacity (grams/denier)	flexibility	heat-resistance	Rot proofness	Bondability	treatment necessary to improve adhesion
steel fiber	7.8	4.0	poor	excellence	poor	poor	nessary

2.3.6 Aramid fibers

Aramid fibers, trade name Kevlar (Du Pont), were the first organic fibers with sufficient stiffness and strength for use in PMCs suitable for airframe applications (Baker, Alan, Dutton, Stuart & Kelly, Donald 2004, 71)

The way to make aramid fibers is to mix terephthaloyl chloride and paraphenylene diamine in an organic solvent to form poly-paraphenylene-terephthalamide (Figure 7) After polymerization, the polymer is washed and then dissolved in sulfuric acid. At this point, the polymer is a partially oriented, liquid crystal form. Then the polymer solution is extruded through small die holes (spinnerettes) in a process known as solution spinning. The fibers are then washed, dried and wound up for shipment. (Hoa, Suong V. 2009,112)

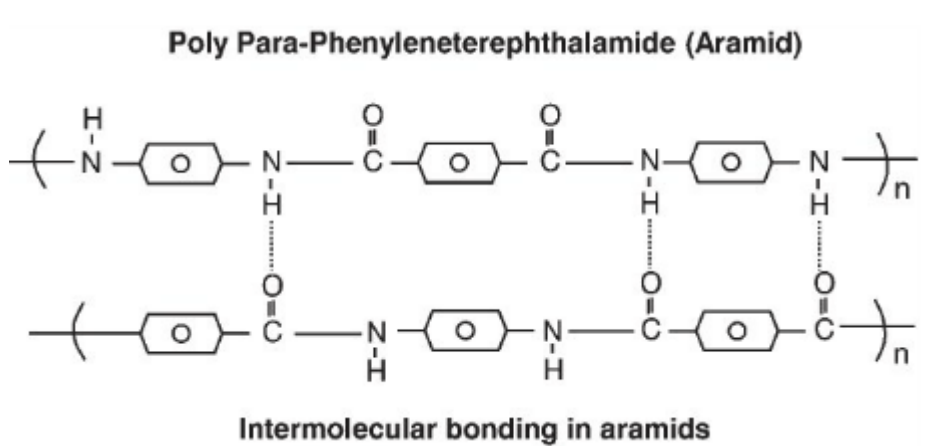


FIGURE 7 Formulation of aramid fibers. (Hoa, Suong V. 2009, 112)

A major advantage of aramid fibers is their ability to absorb large amounts of energy during fracture, which results from their high strain-to-failure, their ability to undergo plastic deformation in compression, and their ability to defibrillate during tensile fracture. The fibers exhibit plastic behavior at around 0.3 % compression strain, and deformation is linear up to failure at strains greater than 2 % in tension. (Baker, Alan, Dutton, Stuart & Kelly, Donald 2004, 71)

Compared with carbon fibers or glass fibers, aramid fibers are less brittle and its tensile strength and modulus are higher.

Due to the presence of the aromatic rings, aramid molecule is strong, but there are only weak hydrogen bonds between the molecules. As this reason, aramid fibers are weak in compression but strong intension.

Aramid fibers can prevent some erosion from most solvents except strong acids and they are prone to absorb moisture. Another property is that aramid fibers will appearance short-term creep but the long-term creep is seldom.

As for the disadvantages of aramid fibers, it will be degraded in strength when it is exposed to ultraviolet radiation for a long time, but this problem is not so big for aramid composites because the fibers are protected by the resin matrix (Baker, Alan, Dutton, Stuart & Kelly, Donald 2004, 73)

Kevlar fibers are made in three different types: Kevlar29 (high tough-ness), Kevlar 49 (high modulus) and Kevlar 149 (ultra-high modulus).Table 11 gives the properties of Kevlar fibers .The modulus increases from Kevlar 29 to Kevlar 49 to Kevlar 149 and is due to changes in process conditions that promote additional crystallinity in the high modulus and ultra-high modulus products

TABLE 11 The properties of aramid fibers

Type of Kevlar Fiber	29	49	149
Tensile modulus (GPa)	83	131	186
Tensile strength (MPa)	3.6	3.6	3.4
Elongation (%)	4	2.8	2
Density (g/cc)	1.44	1.44	1.47

2.4 Prepregs

Prepregs is shortening for preimpregnated. Prepreg is a kind of fibres which is preimpregnated with matrix resin cured to tacky semi-solid structure (B –stage). A prepreg is a composite that comes with the resin already added to the reinforcement. This means that the only concern when working with prepreg is shaping the part. Since the resin is already mixed (resin and catalyst) there is a limited shelf life. For the same reason prepreg must be cured in an oven or autoclave.

According to the nature of fibers, prepregs can be divided into the various types: unidirectional prepreg, woven fabric prepreg, multidirectional tape-prepreg and tow prepregs. (Ratna, D. 2009, 296)

Prepreg can be used in different ways. In terms of applications, the prepregs can be divided into two categories. They are general-purpose prepregs and high-performance prepregs. The high performance prepregs are used for aerospace applications. (Ratna, D. 2009, 296) It can be placed against a mold similar to the hand lay-up method. Once placed in the mold the material must be compressed and cured according to a specific pressure/temperature cycle. This is often done by means of a vacuum bag where a thin plastic cover is secured overtop of the composite and the air is vacuumed out. This process can reduce manufacturing time and produce a stronger part if a knitted preform is used. Another process used is ‘automated tape lay-up’. This process uses a large automated roller similar to a packing tape roller. The roller applies the tape with pressure which eliminates the need for a vacuum bag. Automated tape lay-up is used to produce large parts, generally in aerospace applications and it is also possible to use capable of 3-d parts. (Casey K, PPT 51)

2.5 Coatings for composites

Coatings can be seen as a protective layer for composites in order to provide a wide application. Thermal Spray Solutions offers a variety of coatings that can be applied to composite substrates. (Thermal Spray Solution 2011, web) Composites have a wide range of usage in industries because of its excellent strength to weight ratio. Thermal spray coatings can enhance the surface properties of composites to provide wear resistance, thermal barriers, EMI/RFI shielding, and corrosion. (Thermal Spray Solution 2011, web)

Generally, carbon or glass fibers reinforced with a number of polymer resins such as polyester, epoxy, vinyl ester and phenolic are the most commonly used composite materials for the use of thermal spray coatings.

In addition, coating materials often choose zinc, aluminum, chrome oxide, tungsten carbide, aluminum oxide, anyttria-stabilized zirconia as the typical coating materials. These materials, to some extent, are likely to provide useful properties, such as: protection against heat and fire, electrical insulation and protection against wear, abrasion and physcial damage.

3 PROCESSING OF COMPOSITES

Not only the properties of matrix and fiber will affect the final properties of a composite, but also the processing of some materials will influence the final productions, especially for the composites which are made from the same reinforcement and resin. The applications of composites are very wide including low-tech application (e.g., toys, household appliances) and high-tech applications (e.g., aerospace applications). With an increasing number of composites needed, selecting a particular processing is becoming more and more important. A suitable processing is able to get a good property of composites and reduce the cost of operation. In this chapter, a lot of processing techniques will be discussed and Table 12 shows a comparison between different processes.

TABLE 12 Comparison of various processing techniques (Ratna, D. 2009, 291)

Process	Advantage	Limitation	Preferred matrix
Contact moulding	Low tooling cost, simple process, no shape restriction	Labor-intensive, high volatile emission, slow production rate	Epoxy, polyester, vinyl ester
Compression moulding	Low cycle time, low volatile emission, structural integrity	High tooling cost, average finish	Epoxy, polyester, vinyl ester, polyimide, cyanate ester
RTM	Variety of reinforcement, closed mould, good tolerance	Medium production time	Epoxy
RIM	Fast cycle automation	Resin selectivity	Polyurethanes
Pultrusion	continuous process, low tooling cost, easy to handle	Joining difficulty, shape restriction	Polyester
Filament winding	continuous process, control of fibre orientation, automation	Expensive tooling, slow production rate, shape restriction	Epoxy, polyester
Prepreg moulding	High-quality product, reproducibility, no need of impregnation, minimum material wastage	High cost	Epoxy, bismaleimides, polyimide

3.1 Contact Molding

Contact molding is a well-known and simple method and its curing is at room temperature. Many glass- or carbon fiber-reinforced composites using epoxy, vinyl ester, and unsaturated polyester as a resin are commonly produced by this method. By using this method it is possible to produce a wide variety of structures without any concern about the size and complexity of the shape of the structure. However, the process is very labour-intensive and time-consuming, so is used only for a short run or one-off production. (Ratna, D. 2009, 290)

Wood, plaster of Paris or metal can be materials for making a mold. In contrast with wood and plaster of Paris, metal are a good material for making a long-run mold. At the beginning of this processing, a release agent (e.g., waxes, polyvinyl alcohol) is needed to prevent final products from sticking to the mold. By using a spray gun or a painting brush, a gel-coat is applied into the mold after the application of release agent. A gel-coat is generally a resin-rich layer of thickness about 0.5 mm which provides a smooth, hard surface and prevents fiber reinforcements appearing on the surface. (Ratna, D. 2009, 291) Besides, using a suitable colorant allows a gel-coat provide with a particular color. After this, a resin layer and pre-sized reinforcement will be coated in the mold gradually. Alternate layers of resin and fibre reinforcements are applied until the required thickness is built up. (Ratna, D. 2009, 291)

Nowadays, to increase the production rate, hand lay-up technique is replaced by spray-up technique which uses a multiple-headed spray gun. By using this gun, the chopped fibers and the resin mixture are discharged at the same time to make a even thickness on the surface of the mold. Truck bodies, auto body parts, building components, storage vessels and boat hulls are made using this process.

3.2 Compression molding

Compression molding is a matched-die process that can be used to produce unreinforced resins and fiber-reinforced composites and this process is well-known for its fast cycle time, high reinforcement content, structural integrity and good finishing. The process can be seen from the Figure 8.

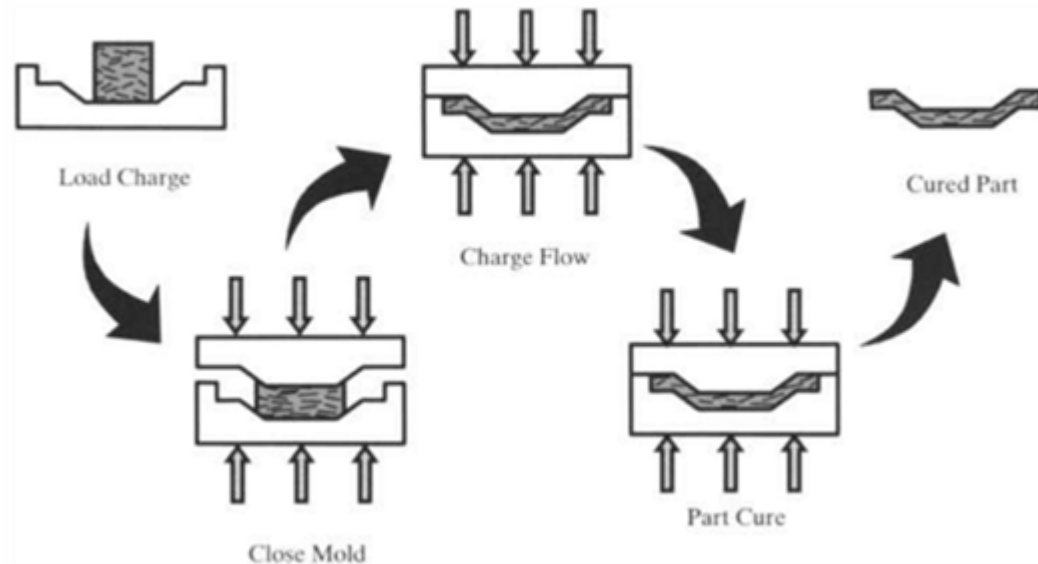


FIGURE 8 Compression Molding (Campbell, F. C. 2004, 24)

A charge of predetermined weight which contains certain fibers and resins is placed between the two dies and then the die will close and is heated and pressurized. At this time, the charge will be melt to fill all the spaces of the molds and cures in 1-5 min. The time varies according to the type of polyester or vinyl ester used. The resin and fiber can be combined by usual hand lay-up or spray-up techniques. Glass fiber content up to 70 WT-% or 50 VOL-% can be achieved for fiber composites processed by this technique. (Ratna, D. 2009, 292) In the field of automotive industry, compression molding is often used to produce thermo-plastic composites which consist of polypropylene and glass fiber.

3.2 Resin Transfer Molding

Resin transfer molding (RTM) is another matched-die process and its products also have a good surface finish and good dimensional tolerances. Compared with compression molding, RTM is different in first steps, in another words, reinforcement is put into mold before the resin is inserted into the mold. Resin transfer molding shown in Figure 9.

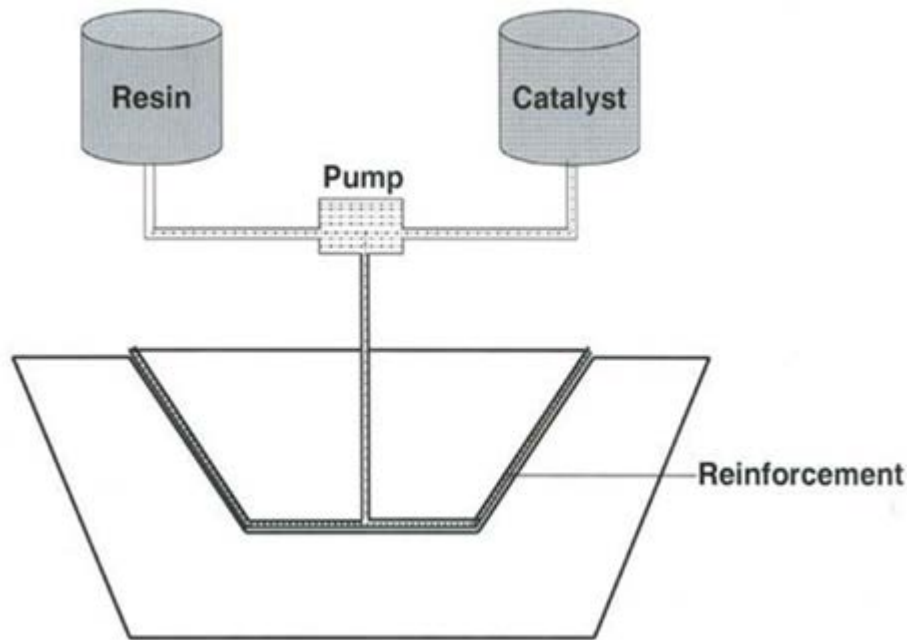


FIGURE 9 Resin transfer molding (RTM) (schematic) (Ratna, D. 2009, 293)

In this molding, the knife/scissor or pattern cutter are used to cut the reinforcement into a desired shape and putting individual layers of fiber into a right orientation to form a preform. After that, a fast curing resin or a small amount of thermoplastic binder is added on the surface of the reinforcement to help the preform to be pre-rigidized. For high-performance applications, a matched lightweight tooling will be used to offer some pressure, making the preform be compressed. When the preform is ready, it will be put into the mold and the mold is closed. Then the mold cavity will be filled by injecting a resin through one feeding hole. If the size of the composites is too big, the feeding hole will be added accordingly. When the resin is filled by the pressure, air in the cavity can be expelled and resin can impregnate the fiber adequately. This process continues till the resin begins to flow from the vent area of the mold. Depending on the different composites, the mold is kept at the curing temperature for several minutes or hours. The post-curing treatment which completes the residual curing reaction of resin will be started after curing. The advancements of RTM are that this processing can offer rapid production, easy to change the reinforcement, low volatile emission and a quality product. Therefore, panels, bumper beams, helicopter components, missiles, propeller blades, compressor casings and satellite discs can be made in RTM.

3.3 Injection Molding

Injection molding (Figure 10) is mainly used to produce thermoplastics which have higher toughness than thermoset with chopped glass, for this process will be faster. Small-size and medium-size parts are normally produced by this process.

In the injection-molding process, resin combined with pellets which contain chopped fibers and embedded fibers are fed into a hopper. They are heated under a certain temperature and injected into a metal die. This process is operated under high pressure. The new cycle is started after the curing for thermoset part or cooling for thermoplastic part

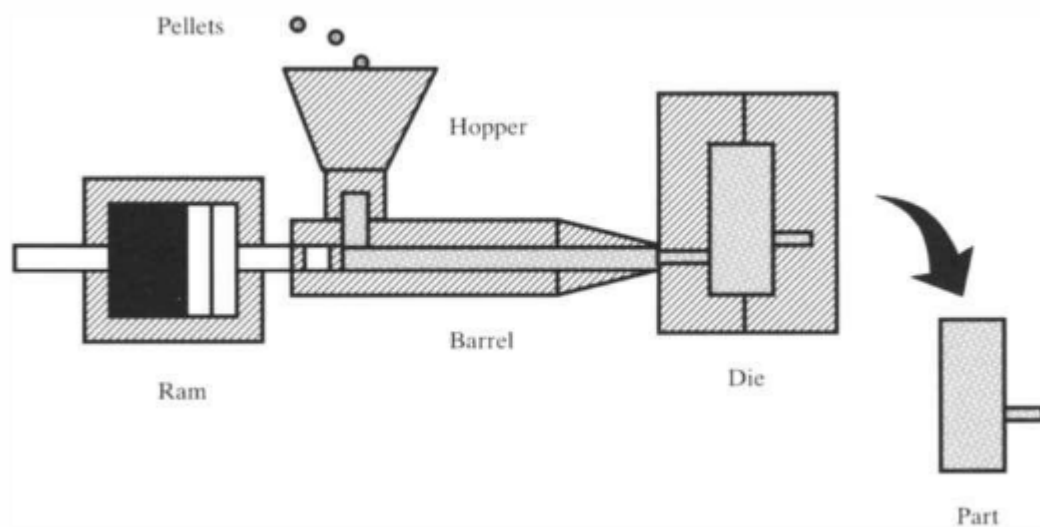


FIGURE 10 Injection Molding (Campbell, F. C. 2004, 24)

3.5 Pultrusion

Pultrusion, illustrated in Figure 11, is a technique which is used for making a product based on continuous fibre or fabric and unsaturated polyester resins (or other resins like epoxy, vinyl ester). The machine has six parts: a creel for offering a continuous fibre, a resin tank, die, pull rollers and a saw to cut the product into a small size. The advantages of this technique are specific strength of the product can be made; various product profile can be produced and easy handling. However, pultrusion has difficulties in joining the products and tooling used is so expensive.

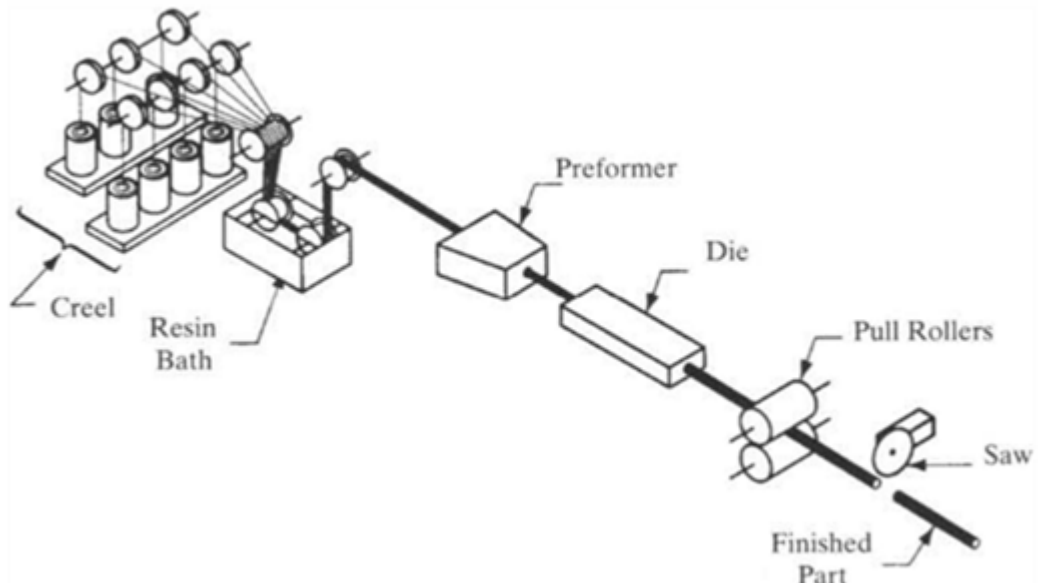


FIGURE 11 Pultrusion (Campbell, F. C. 2004, 25)

The continuous fibres or fabrics are normally passed through a bath which contains a mixture of resin and curatives. Entrapped air and excess resin will be removed when the fibre is passed through a series of rods in the resin bath. The fibre with a wet resin will be performed to the desired shape before going to a heated die. Curing happens in the die to make a rigid composite structure and the cured part will be cut in to a desired length using a saw. The process is called pultrusion because the raw materials are pulled through the combining, shaping and curing operations. (Ratna, D. 2009, 295)

The process is much similar with extrusion which is another processing for making thermoplastics. In extrusion the thermoplastic is forced through the die from inside by a rotating screw; in pultrusion the thermoset material is pulled through the die orifice from the outer side. (Ratna, D. 2009, 295)

Using this technique can produce hollow and solid products with high strength and stiffness and A fibre volume fraction of >50 vol % fibres can be made also. Typical products made by pultrusion are pipes, stanchions and building parts.

3.6 Prepreg molding

As mentioned in the chapter 2, Prepreg is a kind of fibers which preimpregnated with matrix resin cured to tacky semi-solid structure (B –stage). And according to the nature of fibers, prepregs can be divided into four types: woven fabric prepreg, unidirectional prepreg, tow prepregs and multidirectional tape-prepreg.

During manufacturing prepreg tapes, the common process is solvent impregnation. The ribbon or the fabric can pass through a bath filled with resin solution. After passing through some nip-rollers, the ribbon absorbs the resin solution. The gain resin is squeezed off in this process and the fiber can be moisture enough. According to the fiber-to-resin ratio, the rollers are designed. The viscosity of resin mixture can be affected by the solvent. The solvent is used to decrease the viscosity, thereby promoting better impregnation. The solvent can be removed because that the fabric passed through a heated drying chamber. The dried fabrics are partially cured with a limitation about flow and tack. Such prepregs covering with the plastic film wound on a drum. And they stored in a freezer where the temperature is less than -15 °C.

The complex process with feeding of reinforcements, resins and hardeners can be avoided because of the hence by using prepregs. The resin impregnation can be avoided a variable in contrast with another process, such as compression or contact molding. The resin impregnation is a significant parameter in contact or compression process. As a result, comparing with another process, this process is simple.

The prepreg sheets are required to cut a specific shape. A gel coat can be smeared on the surface of the mold. The prepreg layers can be placed on top of one another with a suitable angle. The manufacturer can make a prepreg-based composite by vacuum bag molding. Figure 12 indicates the structure of the vacuum bag. The release layers can make the surface non- sticky and the air bleed layers in order to absorb the gain resin coming out from the prepregs. (Ratna, D. 2009, 296)

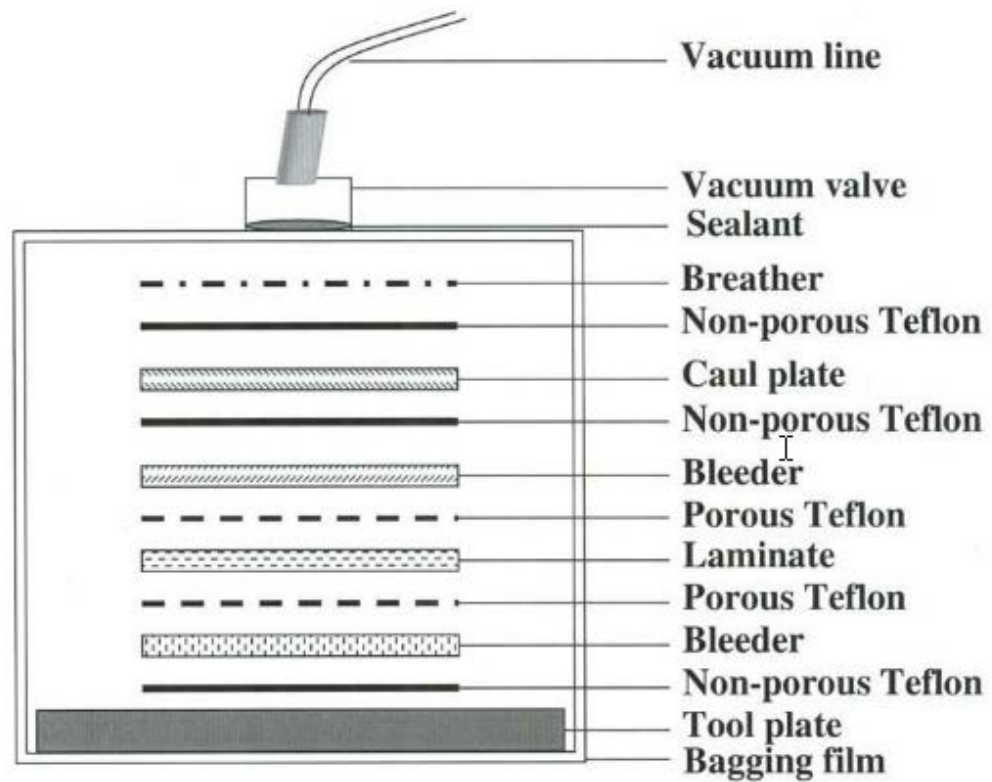


FIGURE 12 Typical vacuum bag configuration used for processing of prepreg

Prepreg molding can bring excellent properties to the composites. It has a range of the applications in aerospace industries because lightness and the mechanical properties of the composites. (Ratna, D. 2009, 296-297)

4 TESTING

4.1 Testing of Composition

4.1.1 Testing of fibers

The properties need to test at low temperatures are elastic modulus and the fracture strength and it is necessary to test the properties about creep properties such as the creep-rupture strength, time and strain-to-failure for high temperature.

The properties of most fibers in the culture are random, so many fibers have to be tested and the figure 13 generated should be statistically analyzed. The properties of fiber be measured on a material stand for the properties of the material.

The standard method for measuring the properties of fiber is the single-filament tensile test (ASTM D3379). Random selections of fibers from material are tested in this test. The fibers are centerline-mounted on special slotted tabs (figure 13). The tabs are clamped so that the test specimen is aligned axially in the grips of a test machine. It is necessary to measure the cross-sectional area carefully. The axial strain is measured by the noncontact-type extensometer.

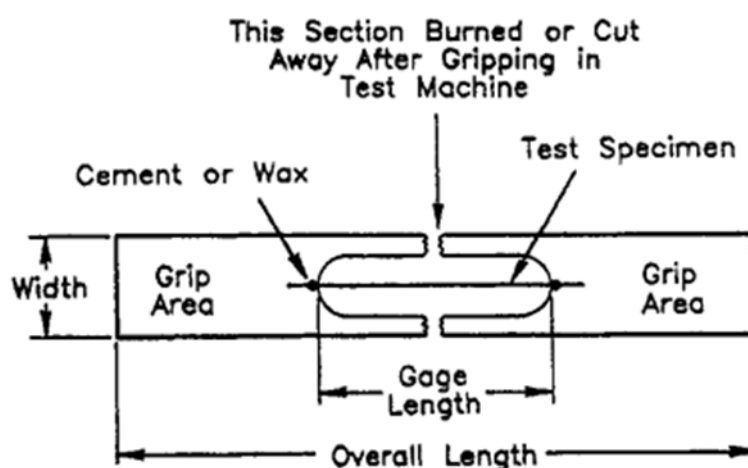


FIGURE 13 Fiber testing method (Buschow, K. et al. 2001, 5272)

4.1.2 Matrix Ignition Loss

Matrix ignition loss is a basic method for knowing the fiber, resin and void content in a composite.

ASTM D2584 and ASTM D3171 are used in this test method. “Stand Test Method for Ignition Loss of Cured Reinforced Resin” is ASTM D2584. In this test, a pre-dried and weighted composite specimen is placed in a crucible which has a known weight and then putted in a furnace. Then the organic resin matrix will be burn of. The next step is cooling the crucible in a desiccator. After that it will be reweighted. The amount of the loss in weight before and after burning stands for the resin content of the composite sample. The left weight shows the fiber reinforcement and any inorganic fillers in the composite. (Louis C. et al. 2009, 155)

This test indicates that combustion can’t affect the fiber reinforcement. The fiber reinforcement is general used with fiberglass-reinforced composites and other composite reinforcements which are insensitive to high temperature like silica. (Louis C. et al. 2009, 156)

4.1.3 Matrix Digestion

Matrix digestion is the other basic method for knowing the fiber, resin and void content in a composite.

The acid digestion method use ASTM D3171 which is commonly explained as “Stand Test Methods for Constituent Content of Composite Materials.” Different composite material use different methods.

I The matrix will be digested or ignited using some procedures. The reinforcement will stay. It is the essential material which is unaffected in whole process. In this test, the reinforcement content and the percent void volume can be calculated.

II This method is just used in laminate materials which have known fiber weight. The test can calculate the reinforcement or matrix content by volume or weight. (Louis C. et al. 2009, 156)

4.2 Mechanical Test Methods

4.2.1 Fatigue test

Fatigue test is a kind of test to determine the fatigue characteristics of a material by subjecting a test specimen to cyclic loads. (Tomsic, Joan L. 2000, 167) In most cases, a constant load is not operated in some structures. In fact, the tester usually uses the constantly changing stresses in a composite structure. This constant change in stress can lead to fatigue failure where the material breaks suddenly. A complete fatigue test should include a series of statistical analysis where the worst case states of stress (like turbulence, take-off and landing) and amplitude stresses which can be measured in order to know the long-time fatigue behavior. (Louis, C. et al. 2009, 153)

A cyclic load is offered to a specimen until it breaks in order to measure the fatigue resistance of materials. The fatigue life (N_f) which means the amount of cycles to failure need to be recorded. The logarithm of this number is plotted against the stress to develop an S-N curve (stress versus number of the cycles to failure). Sometimes the log of stress can be used. Figure 14 shows us an example about S-N curve. This curve indicates the fatigue resistance of the material. In fact, it is must that a great many of the tests to run.

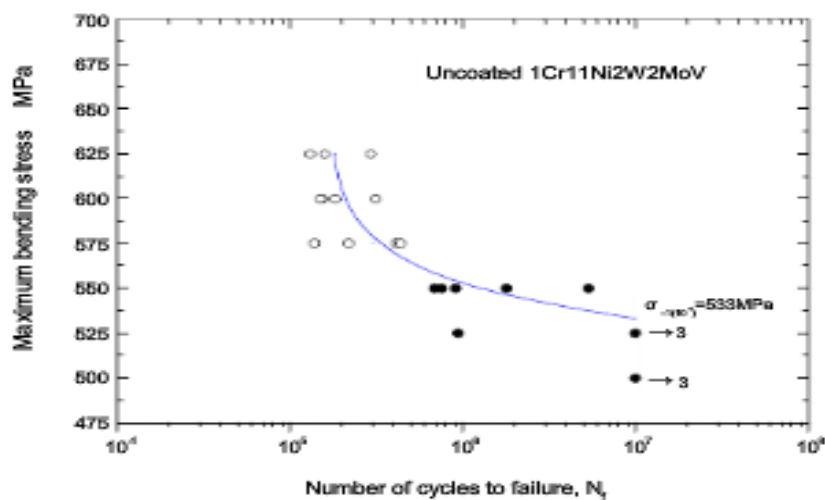


FIGURE 14 A sample about S-N curve (Steinmetz, P. et al. 2008, 229)

“Standard Test Method for Tension-Tension Fatigue of Polymer Matrix Composite Materials” (ASTM D3479) is common used to determine the fatigue behavior of polymer matrix composite materials subjected to tensile cyclic loading. However, it is not suitable to use this method in un-notched test specimens subjected to constant amplitude uniaxial in plane loading. (Louis, C. et al. 2009, 154)

4.2.2 Tensile

The tensile test is characterized to perform σ – ϵ behavior of multidirectional fiber composites. The borderline states 0° and 90° orientation is different. When 0° specimens are used, fiber strength is a main factor in the composite strength, whereas when testing use 90° specimen, the test result is influenced by matrix strength, fiber–matrix interface strengths, as well as internal stresses and pores. (Grellmann, W. & Seidler, S. 2007, 523)

Straight-sided dog-bone type loaded specimens with rectangular cross-section are commonly used for measuring the in-plane tensile properties of unidirectional, as well as cross-ply, composite laminates (ASTM D3039 for PMCs and D3552 for MMCs). Test specimens with round or tubular cross-sections can also be used. An important factor for obtaining highly accurate test results is minimization of the specimen misalignment with the load train and the resultant bending stresses. Likewise, good alignment between the desired fiber orientation and the specimen axis is a must.

The sandwich beam test (ASTM C393) for measuring the flexural properties of flat sandwich constructions. This test is also useful for tensile testing, particularly for the 90° properties of unidirectional composites. (Buschow, K. et al. 2001, 5272)

ISO 527-4 and ISO 527-5 are the relevant international standards for tensile tests on fiber composite materials. According to the laminate structure, there are so many types of specimens in the testing. In ISO 527-5, the specimen type is defined for unidirectional fiber composites. In ISO 527-4, three different specimen geometries are permitted for isotropic and anisotropic fiber composites. Type 1 can be used for fiber-reinforced thermoplastics and thermosets, if they break within the measurement length. Type 2 and

type 3 can be used in multidirectional composites. (Grellmann, W. & Seidler, S. 2007, 523)

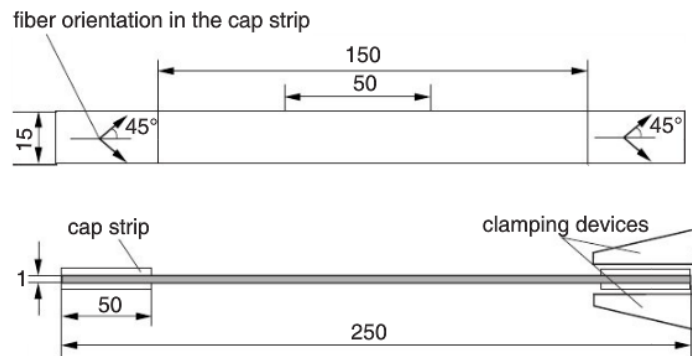


FIGURE 15 Specimen type for tensile tests on UD laminates according to ISO 527-5

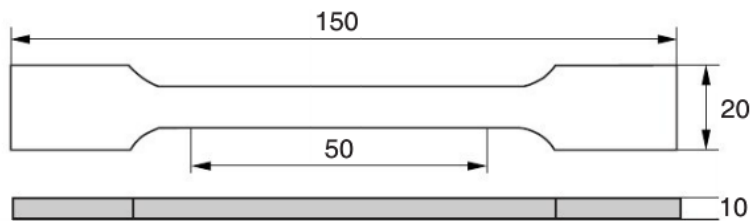


FIGURE 16 Specimen type 1 for tensile test according to ISO 527-4

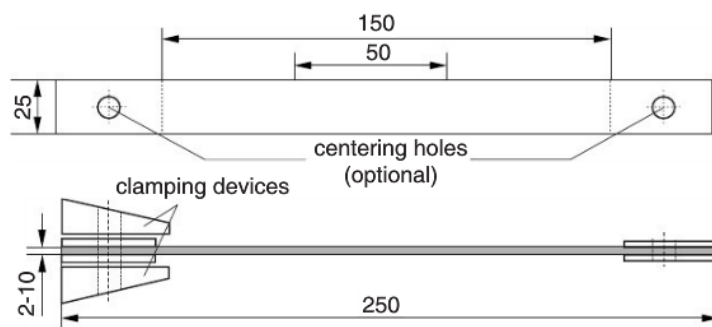


FIGURE 17 Specimen type 2 for tensile test according to ISO 527-4

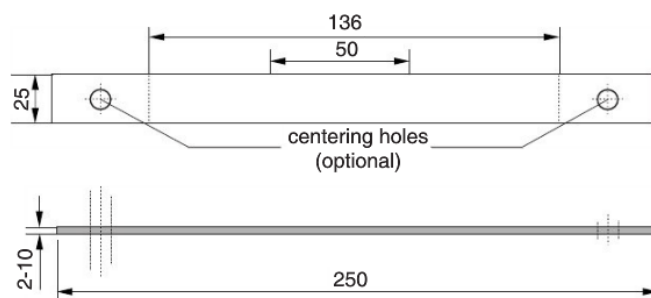


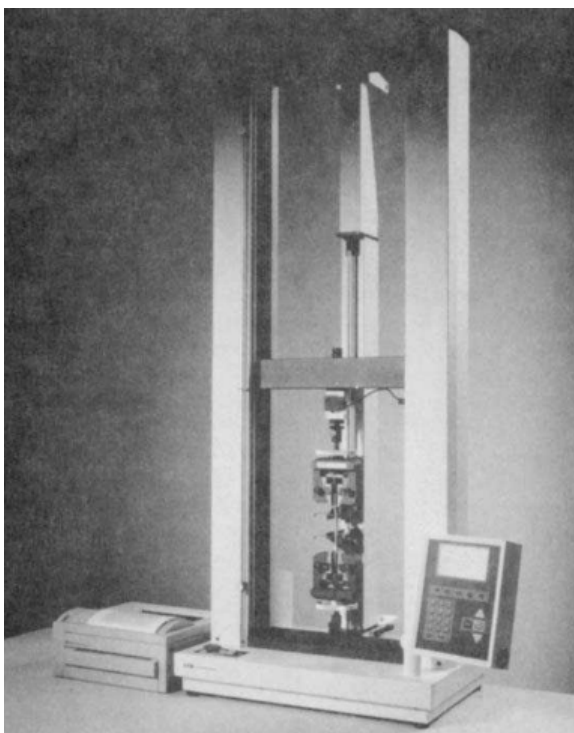
FIGURE 18 Specimen type 3 for tensile test according to ISO 527-4

(Grellmann, W. & Seidler, S. 2007, 523-525)

The tensile test is one of the simplest tests to perform. The gage length (uniformly reduced section) of the sample depends on the design requirements. Standard sizes are 0.5, 1, and 2 inches. The gage section length has the smallest diameter, so it has the highest stress (load/area). Tests can be performed at almost any temperature in almost any environment provided a suitable chamber is designed and built for testing. It is common to test at both room temperature and elevated temperature. Air is the most common environment to test in. (Pope, J. & Edward 1997, 285)

The cross-section can have nearly any shape, although circular and rectangular are the most common. The cross sectional area has some influence on the strength properties, with thinner samples having higher indicated properties. The shape is often dictated by the form of the material; flat plate will generally be tested as flats or sheets while bar stock may be tested in the round. Further, plate stock may be tested parallel to the rolling direction, long transverse, or short transverse. The properties will vary greatly with the orientation of the stress axis with respect to the rolling direction. Forgings are also grain orientation dependent, and more than one direction is tested to characterize the properties. (Pope, J. & Edward 1997, 285)

Tensile properties of fabric-reinforced composites were characterized in accordance with ASTM D3039/3039M-08. Tensile tests were carried out using a universal mechanical testing machine (Intron model 3367). The machine was operated at a crosshead speed of 5 cm/min and a gauge length of 140 mm. Five specimens were tested to obtain average tensile properties (Staab, G. 1999, 114)



PICTURE 6 Tensile testing machines (Shah, V. 1984, 18)

4.2.3 Compressive

Comparing with tensile testing, compression testing of composites is more difficult. The reason about failure related to some types of buckling, ranging from classical column buckling of the entire specimen to local micro buckling of the individual fiber. So in this test, it is necessary to avoid buckling. Nowadays, many axial compression tests are just a variation of the Celanese compression test (ASTM D3410). In this method, a thin, straight-sided specimen with a small gauge length (- 13mm) is loaded in the tabbed region using inverted cone wedge grips. (Buschow, K. et al. 2001, 5274)

Compression test shows that the strength of a columnar sample supported on its sides to prevent buckling when it is pressed on its end. There are various test methods at present. The common method for compression test is the modified Boeing test methods, which is almost same with the procedure and fixture given in ASTM D695. It consists of metal plates between which the tabbed sample is placed.

In this case, the tabbing extends along both sides of the sample except for a small region (.50 in. [1.3 cm]) in the middle. The support fixture prevents the sample from buckling. However, it doesn't prevent the non-tabbed region from failing. Pressure is applied only on the end of the sample. Other compression test systems include those developed by

Celanese, Illinois Institute of Technology Research Institute (IITRI), and the National Aeronautics and Space Administration (NASA). These methods differ principally in the way the sample is supported by the fixture.

The compression test after impact test is a significance test to measure the loss of properties after impact. In this test, some flat –panel sample are made. The special fixture is placed on the sample's sides and bottom. A cap is placed on the top of the sample where the compression machine presses. Then the flat –panel compressive strength can be tested by using a control sample. Then, other specimens are impacted with a known energy and then tested for flat-panel compressive strength. The compressive strengths are compared to evaluate the effect of damage to the composite sample. (Strong, A. Brent 2008, 280)

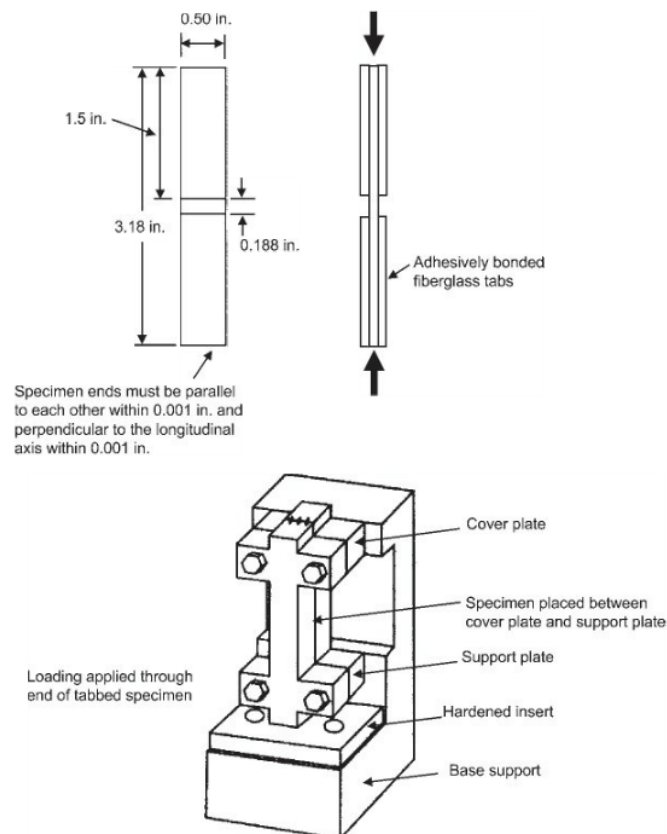


FIGURE 19 Modified ASTM D 695 compression test(F.C. Campbell 2010, 355)

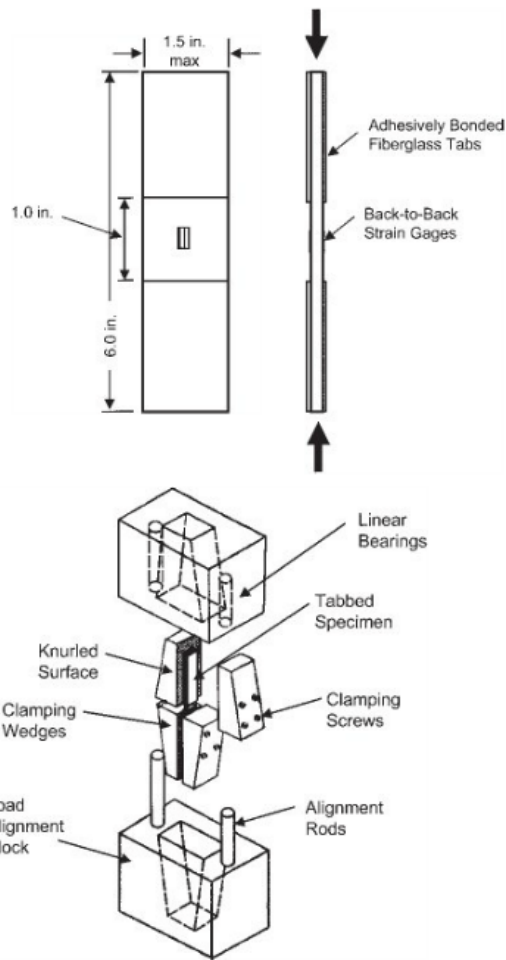


FIGURE 20 IITRI compression test (F.C. Campbell, 356)

4.2.4 Shear

Shear testing is a hard area to define a consistently accurate test. ASTM D5318 is generally used in the V-Notched Beam Method or Iosipescu Shear Test. (Louis C. Dorworth; Ginger L. Gardiner; Greg M. Mellema 2009, 150)

In this test, the tester can use a simple method. The process includes molding a sample with turned ends. (Strong, A. & Brent 2008, 281)

It can be done in tensile machine. A flat rectangular coupon is used. There is a symmetrical v-notch on opposing sides of the coupon in the midpoint. The coupon is placed in a fixture. There is a push power downward by a cross-head of the fixture. The fixture let a shear load into the coupon the coupon between the notches. The deformation can be

calculated by strain gages. Figure 21 shows Losipescu V-notched beam shear test. (Louis C. et al. 2009, 150)

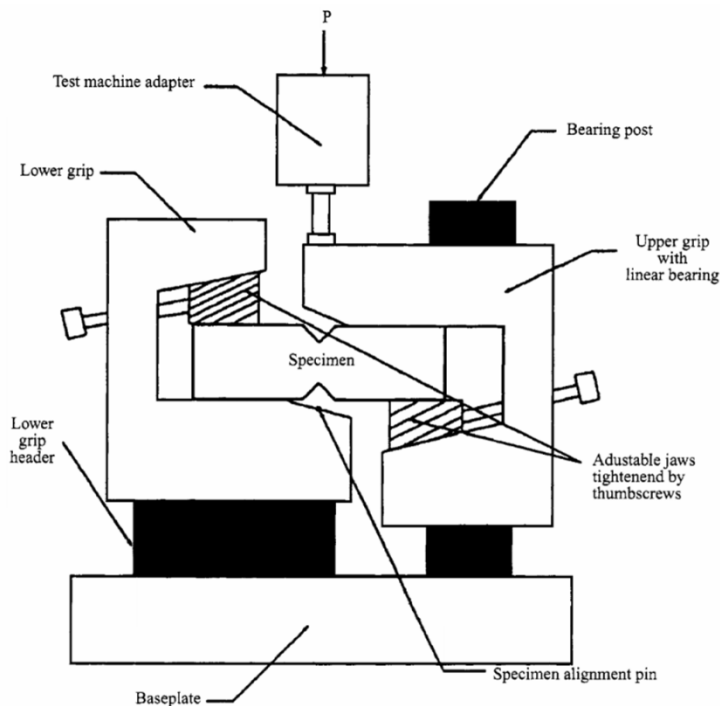


FIGURE 21 Losipescu V-notched beam shear test (Louis C. et al. 2009, 150, modified)

4.2.5 Flexural

The original ASTM D790 can be used in unreinforced plastics. After modifying it can be used in composites.

In flexural test, the rectangular sample is placed by two supports. And it will be pressed on the top of the sample. The situation with a single point of contact is often used in this test, which called the standard flexural test or the three-point bend test. Figure 22 shows that this test. However, sometimes the tester can use two point of pressure which is called the four-point bend test. Figure 23 indicates the three-and four-point flexure tests. In this test, the top of the sample under the loading power is in compression and the bottom opposite the loading power is in tension. It is easy to perform the flexural test. It is the mixture tensile and compressive force, which it means the flexural test cannot indicate the basic material properties in theoretical calculations for design.

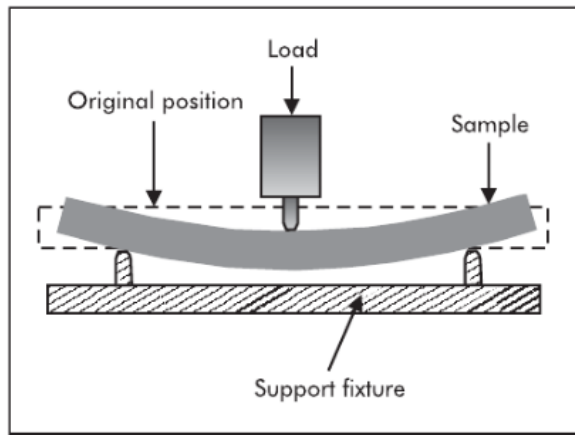


FIGURE 22 Flexural test (Strong, A. & Brent 2008, 280)

In fact, if the coupon does not fail in its outside surface with 5.0 % strain limit or does not break, the flexural strength cannot be determined. The specimen is deflected until the outer fiber strain reached 5 % or it break. (Louis C. et al. 2009, 152)

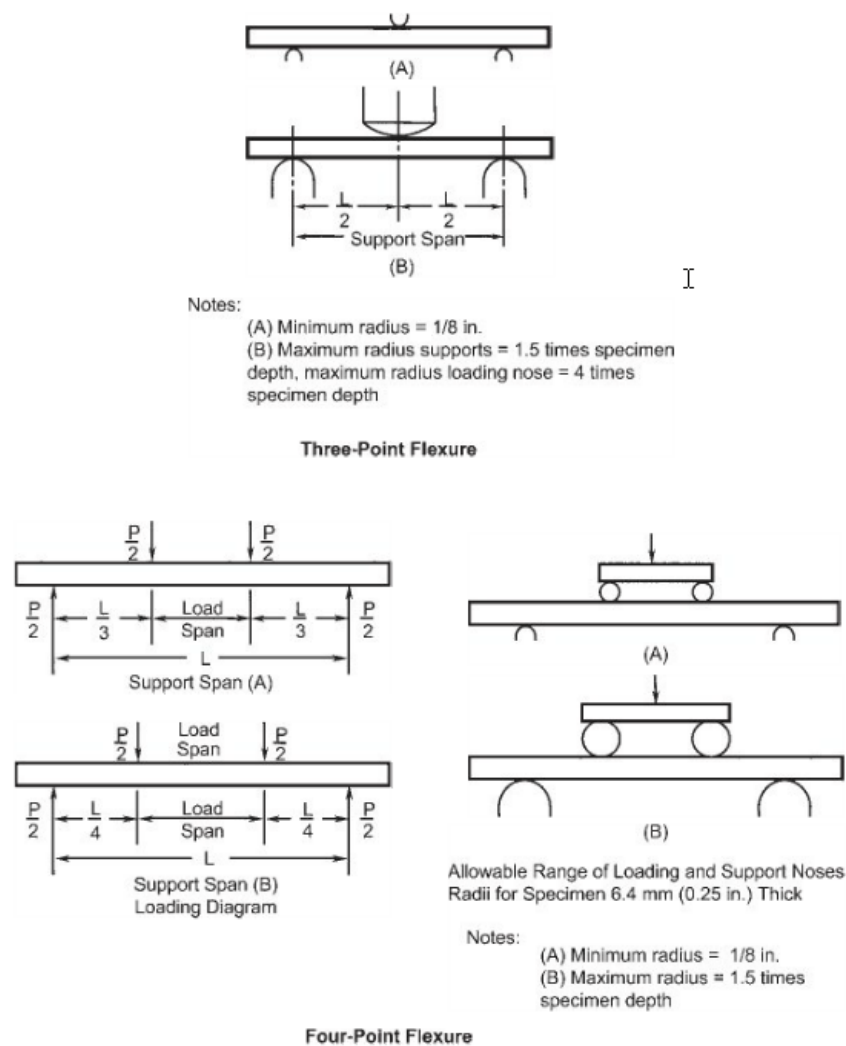


FIGURE 23 Three- and four-point flexure tests (F.C. Campbell 2010, 353)

4.2.6 Impact

Impact tests can be divided into two classes: pendulum impact tests and drop-weight impact. And each test can be subdivided into non-instrumented and instrumented. A non-instrument test just shows one feature: total impact energy. It offers for tester extra information about fracture behavior, ductility, yielding or dynamic toughness. The force continuously can be measured in an instrumented test when the specimen is broken. It is easy to record the energy required to break the material and the failure during the impact event can be recorded. (Ratna, D. 2009, 47)

Impact test is a test to measure impact strength of the material under the effect of the impact load. In the experiments, the polymer is damaged by offering a shock load and record the energy value that unit cross-sectional area of the specimen absorbed during the whole process. Because the manufacturing methods and the structure of them are different, their impact strength is also different. In engineering applications, the impact strength is an important performance indicator. Tester can evaluate the degree of brittleness and ductility and the capacity to resistant impact. (Ullmann, F. 2005, 773-774)

Pendulum impact test

The pendulum impact test includes a hammer of pendulum type. There are four ways: Izod, Charpy, Chip and Tensile. The device consists of a heavy base vice be used to clamp the specimen and a hammer. This equipment need to keep a platform to prevent vibrational energy losses.

These Izod/ Charpy test are widely used in industry application, and it is possible to generate comparative data very quickly. (Ratna, D. 2009, 47) The notched bar impact test is a common method of impact testing. It is the most common laboratory test to measure the impact energy. The Charpy V-notch specimen is placed in an impact testing machine and the heavy pendulum is released from a known height h_0 . After striking and damaging the specimen, the pendulum stops at lower. The final height h_f is recorded. The tester can calculate the energy absorbed by fracture because that the mass of the pendulum and its initial and final elevations are known. The energy is usually expressed in joules. In fact, the material has large impact energies if it has both high strength and high ductility. (Ullmann, F. 2005, 773-774)

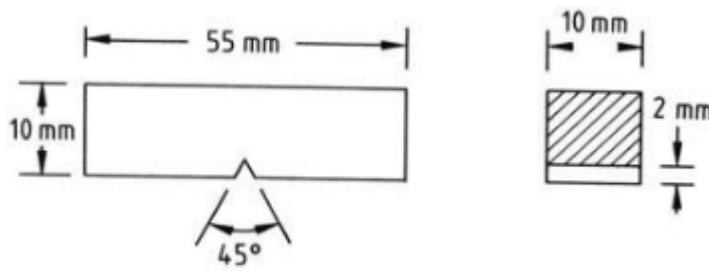


FIGURE 24 Charpy V-notch specimen (Ullmann, F. 2005, 773-774)

They are done as per ASTM D256 using a notched specimen. In the Izod test the specimen is fixed as a cantilever with the help of a vice. (Figure 26) The Charpy test has the same devices, but there is a little difference between them. The specimen is supported as a simple beam in Charpy test. The energy transferred to the material can be inferred by comparing the difference in height of the hammer before and after fracture. According to the instrument, the impact energy (J/m) or the load history during the impact event can be recorded. The test can be carried out using different combinations of impactor mass and incident impact velocity to generate data on damage tolerance as functions of impact parameters, which are helpful for the design of composite materials for a particular application. (Ratna, D. 2009, 47) Energy absorbed in striking the specimen can be recorded by the machine. The energy during the process is changed. Specified average impact energy for the specimens tested must be got at the specified test temperature, fracture energy being dependent on temperature. (Bruce, G. & Eyres, D. 2012, 65)

The Charpy impact test is done in a similar way to the Izod test but without a notch. The size of specimen is usually 25.4 mm long, 12.7 mm wide and 1.65 mm thick. The standard of test is ASTM D4508. This test reflects material toughness rather than notch sensitivity measures for the Izod and Charpy tests because it involves an un-notched sample.

(Ratna, D. 2009, 47)

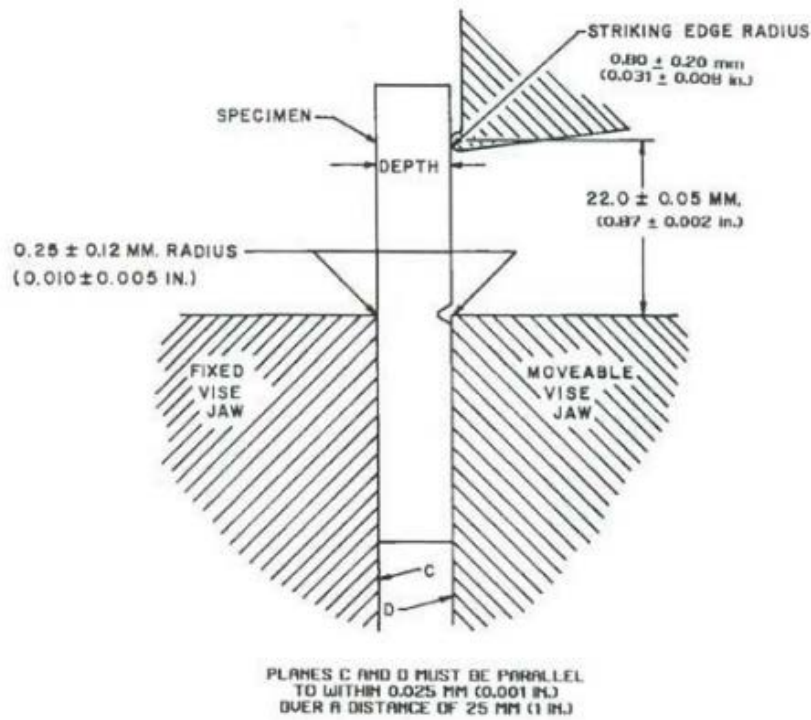


FIGURE 25 Relationship between vice, specimen and striking edge to each other
(Ratna, D. 2009, 48)

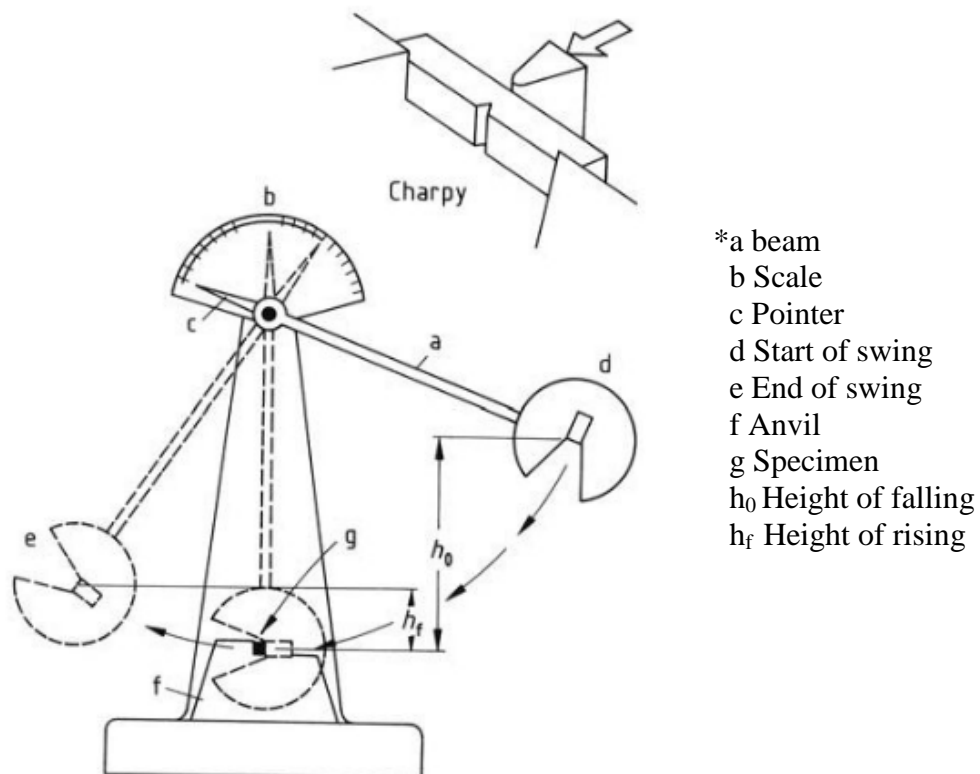


FIGURE 26 The illustrated catalogue about the charpy impact test (Ullmann, F. 2005, 773-774, modified)

Drop-weight impact

Another test used to evaluate thermoset resins and composites is the falling-weight or drop-weight impact strength. The falling weight may be a ball, a tup with a chemical nose or a dart. Depending on the nature of weight and the application, two ASTM standards D5420 (ball, rigid specimen) and D1709 are used for testing thermoset materials. ASTM D2444 (tup) is used for the evaluation of thermoplastic materials. In a dart impact test, the dart is allowed to fall on a specimen kept in a fixture with an annular hole typically ranging from 2.5 cm to 7.5 cm. The output of the load transducer can be directly fed into a signal processor, and the impact energy or the entire loading history recorded using an instrumented machine. The biggest advantage of the falling-weight impact test over the pendulum impact test is its ability to reproduction the multidirectional impact stresses that a structure or part would be used in the actual service condition. It also enables specimens of different sizes and shapes and a part as a whole to be tested. (Ratna, D. 2009, 48-49)

Most plastics break in a characteristic manner because the type of molecule, molecular components, method of fabrication, shape of the part, part complexity, orientation and temperature. There are four types of impact failures:

Yielding - Evidence of permanent deformation without cracking

Cracking - Evidence of cracking or yielding without losing shape or integrity.

Brittle - Evidence of catastrophic failure without evidence of yielding. GP polystyrene is a brittle material.

Ductile - Evidence of definite yielding along with cracking. Polycarbonate is a ductile material. (Hylton, D. 2004, 27)

4.3 Non-Destructive Testing

Non-destructive testing is any method of testing that does not damage or destroy the sample. Usually, it consists of stimulating the sample with electricity, magnetism, electromagnetic radiation, or ultrasound and measuring the sample's response (Tomsic, J. 2000, 276)

The reason of using non-destructive testing is to find defects that may affect composite performance. These factors include inhomogeneity within the materials, fiber breakage, voids, porosity and so on.

NDT vs destructive testing

Non –destructive test is used in potential problem areas. However, the destructive test often needs to know problem extent. Both destructive and analysis are required.

Typical NDT Techniques for Composites

There are so many typical NDT techniques for composites, such as visual inspection, ultrasonic methods, X-ray, thermography and so on.

In the test of the visual inspection, the tester can observe some defects including surface damage, bubble, porosity and delamination of edges by eyes or microscope. Ultrasonic test methods used to monitor for delamination, voids, fiber damage and matrix damage by transmission and pulse echo. X-ray inspection detects density changes. It is suited for bonded interfaces. And this test can locate delamination, voids, porosity and moisture. Thermography is used to measure effects from thermal changes by heat transfer. It is useful for locating delamination and contamination. (Dan, A. 2010, PPT, 38-41, 43-45)

5 APPLICATIONS

The application of composite materials is extensive and expanding, including aerospace, construction, sporting goods and marine. The horizontal and vertical tail planes on the Boeing 777 that are made of carbon/epoxy is a good example of aerospace applications. Besides, both commercial aircraft and military aircraft used composites to decrease the weight and increase fuel performance. For decades, helicopters have used glass-fiber-reinforced rotor blades for improved fatigue resistance and in recent years have expanded into largely composite airframes. Composites are also used extensively in both reusable and expendable launch vehicles and satellite structures. (Campbell, F. C. 2004, 32)

Compared with metals and wood, composites do not corrode and this function can minimize the maintenance fee for some marine companies. Glass fibers and polyester or vinyl ester resins are widely used in boat hulls ranging from small fishing boats to large racing yachts. Glass-filament-wound SCUBA tanks are another example of composites improving the marine industry. Lighter tanks can hold more air yet require less maintenance than their metallic counterparts. Jet skis and boat trailers often contain glass composites to help minimize weight and reduce corrosion.

5.1 Aerospace industry

Since 1940s, the glass fibers firstly introduced in aerospace industry and its use with polyester and epoxy resins in postwar lay a foundation for the development of composites using in the aerospace industry. Nowadays, a light weight composite materials are increasingly needed in modern light aircraft. High-strength carbon, glass-fiber and Kevlar[®] composites are used in helicopter rotor blades, wing spars, flooring, nose and landing gear doors, air distribution ducts, drop tanks and so on. The first Boeing 707 had approximately 2 % composite construction. In contrast, today's Boeing 767 has approximately 50 %, and the Beech Starship was the first certified general aviation aircraft to have a structure built entirely of composites. The Bell-Boeing V-22 tiltrotor aircraft is also the first of its kind to be made entirely of composite materials. Some aircraft using considerable amounts of composites are as follows. (Armstrong, Keith B., Bevan, L. Graham & Cole, William F. 2005, 6)

Aerospatiale:	ATR 42 and 72 and others in this series
Airbus:	A.300, A.310, A.318, A.319, A.320, A.321, A.330, A.340, A.350, A.380, and A.400M
Boeing:	717, 737, 747, 757, 767, 777, and 787 Dreamliner
BAE Systems Regional Aircraft Ltd.:	146, RJ Series, Jetstream Series
Fokker:	F.50, F.70, and F.100
Boeing/McDonnell-Douglas:	M.D.11 and C.17

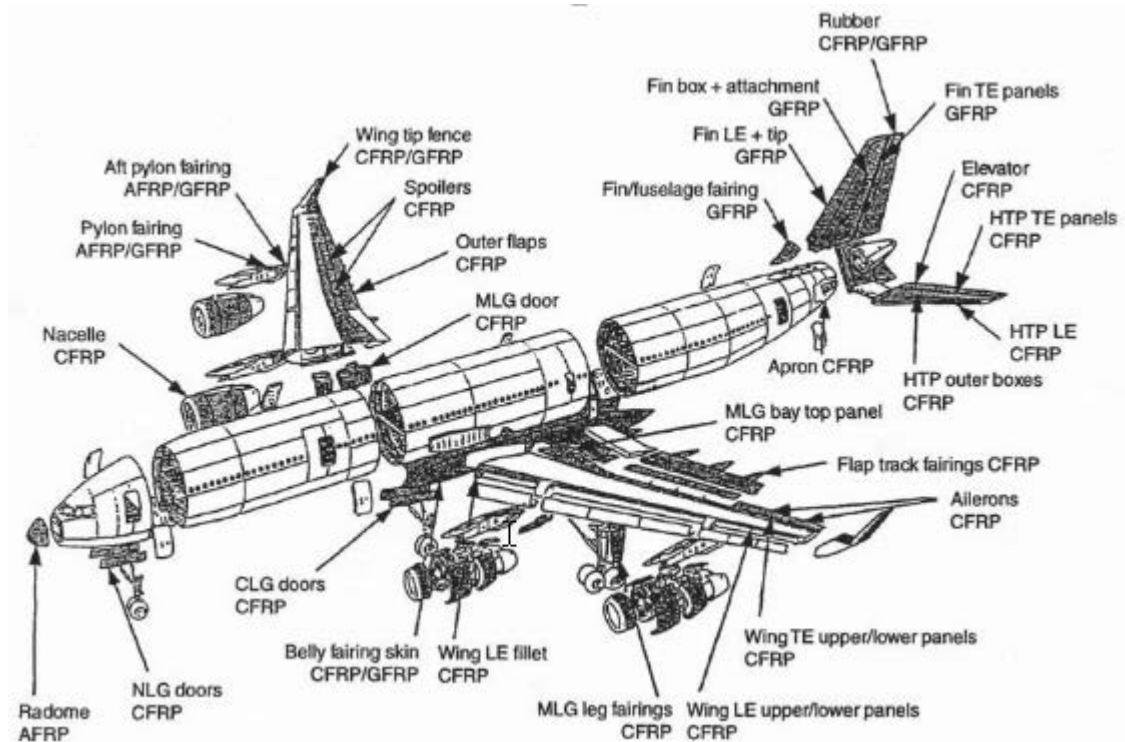


FIGURE 27 Use of composites on the airbus A.340 (Courtesy of Airbus Industry) (Armstrong, Keith B., Bevan, L. Graham & Cole, William F. 2005,7)

5.2 Construction



PICTURE 7 Composites used into construction (The new world of fiber-based materials, Web, 2014)

For the past few decades, fiber reinforced polymer (FRP) composite materials are mainly used into the aerospace industry. Recently, civil engineers and the construction industry began to realize the potential of these materials in providing remedies for many problems associated with the deterioration and corrosion of infrastructures. (John Wiley & Sons 2002, 1369) Wood (natural composites), concrete (particulate composites) and plywood (laminated natural composites) were some different composite materials used into construction, but civil engineers found that polymer composites are the best choice. Polymer composites are “engineered” materials that encompass a wide range of materials where two or more, physically distinct and mechanically separable, components are combined together to form a new material that possesses properties that are notably different from those of its individual constituents. (John Wiley & Sons 2002, 1369)

Among the component, fibers play a primary load-carrying role, they can be in different types, shapes and grades. Glass (E, S, A R grades), aramid (Kevlar), and carbon fibers with different grades are regarded as typical types of structure fibers. As for the matrix, it always act as a binder, a stress distribution phase of the laminate and an environmental protector. In most of the structural application, thermoset resins are preferred. Examples of thermoset resins include epoxies, unsaturated polyesters, vinyl esters, amino, phenolic, and urethane resins. (John Wiley & Sons 2002, 1369-1370)

The durability and resistance to the marine environment is another attractive feature of these materials, their energy absorption under earthquake loading, their low value of coefficient of thermal expansion, pigment ability and decorative characteristics, their toughness, particularly at low temperatures and their high strength-to-weight ratio. These unique properties can be used to produce an optimum structural system with minimum life-cycle cost, fabrication and construction cost, and time. (John Wiley & Sons 2002, 1370)

5.3 Automotive engineering

Nowadays, an increasing number of the continuous and long fiber reinforced polymer matrix composites are used for automotive body and thermoset polymers is the main material in this industry. Compared with thermoplastic polymers, thermosetting polymers are much easier to produce structural composites with high strength and modulus

due to its low viscosity. This property allows the matrix much easier to combine with long and continuous fibers. On the other hand, chemical resistance and heat resistance of thermoset polymers is higher than most thermoplastic polymers. However, thermoset polymers still have its own disadvantages. First, according to the temperature used and curing system, the curing reaction may take several minutes to several hours to complete, which make the processing time much longer than that of thermoplastic polymers. Second, thermoset polymers cannot be reused or recycled because it cannot be returned to liquid state or re-melted.

Applications of thermoset-matrix composites in current automobiles include radiator supports, bumper beams, fenders, hoods, roof panels, deck lids, and a number other exterior and interior body components. There are also a few chassis, suspension and powertrain components where thermoset-matrix composites are used, such as leaf springs, cross members and drive shafts. (Mallick, P. K. 2010, 209)



PICTURE 8 BMW's composite cross-beam.(European composites industry set for slow recovery, Web,2009)

In most of the thermoset-matrix composites used into automotive engineering, E-glass fiber plays a vital role as the reinforcement. The dominant reason is that the price of E-glass fiber is much lower than that of carbon fibers. But when considering the stiffness and load carrying capacity, carbon fiber with greater strength-to-density and modulus-to-density ratios are much more effective than glass fibers. Thus, carbon fibers are likely to be used into future vehicles, like the fun flyer created by Flynano Company (Figure 28). This kind of helicopter is extremely light thanks to the advanced carbon fiber

composite construction. So the carbon fiber is becoming more and more critical in automotive engineering.



FIGURE 28 A fun flyer crated by Flynano company (Flynano, Web, 2014)

5.4 Sports

Perhaps the most visible development in the use of composites has been in the sports goods industry. (Harris, Bryan 1999, 314) Duo to the good properties of composites, such as lightness, good chemical resistance, eases of transport, low maintenance and durability, Manufacturers are making full use of the potential advantages of composites like carbon and boron fiber composites to meet different demands of customers.

At first, the sports equipment is produced in natural materials, like wood. But the main drawback of it is the anisotropic nature which is likely to result in a variation in properties and high moisture absorption. After that, manufactures regarded light metal, like aluminum, as a good material for sports application. However, since aluminum has no fatigue limit stress, even small stresses caused great fatigue. (The new world of fiber-based materials, Web, 2014) Finally, composites which offer fatigue strength, greater stiffness have replaced metals.



PICTURE 9 Tennis rackets (The new world of fiber-based materials, Web, 2014)

Nowadays, fishing rods, boats, canoes and canoeing gear, skis, bicycles, tennis rackets (Picture 9), and protective equipment are mostly made by composites and it should be noted that the composites used into sports equipment varies according to its purpose, table 13 shows some different characters of different fibers and its applications. For example, in some modalities, good shock absorption is needed, as in bicycle frame and tennis rackets, while in others it takes minimum loss of energy, in order to provide higher speeds, like bicycles. (The new world of fiber-based materials, Web, 2014)

TABLE 13 The characteristics and application of different fibers (The new world of fiber-based materials, Web, 2014)

<i>Fibers</i>	<i>Characteristics</i>	<i>Application</i>
<i>Carbon</i>	<i>Lightness and strength.</i>	<i>Bicycle.</i>
<i>Kevlar</i>	<i>Light weight, tensile strength, tenacity and impact resistance.</i>	<i>Skis and protective gear.</i>
<i>Boron</i>	<i>Resistance and good compression properties.</i>	<i>Golf clubs.</i>
<i>Glass</i>	<i>Rigidity, flexibility, low fatigue resistance and high vibration.</i>	<i>Kayaks.</i>

6 RECYCLING

At present, the problem of recycling in composites still is a problem because that the mixture of a great many amounts of fibers or fillers and the wide use of thermosetting matrices which cannot be melting processed. It is a simple method to grind the composites into powder or granules. This powder can be incorporated into a cement-based or thermosetting matrix to form a further composite material which is often found in the construction industry. Figure 29 shows the options available for recycling waste composite materials.

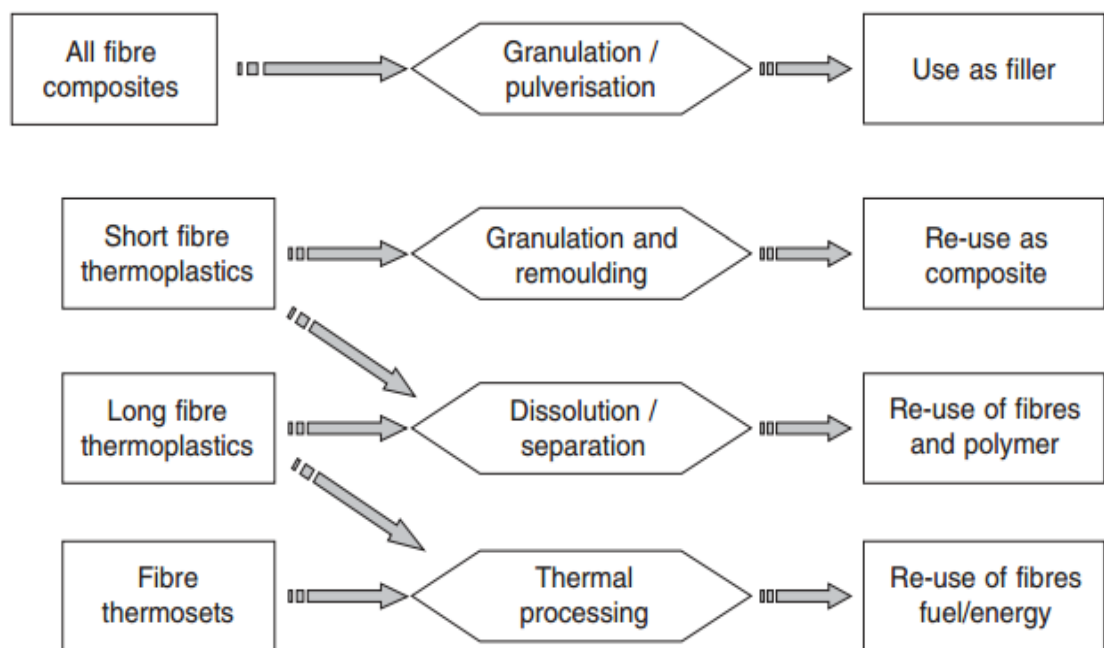


FIGURE 29 The options available for recycling waste composite materials. (Baillie, C. 2004, 292)

The main recycling methods include mechanical recycling method, chemolysis method and thermolysis method. The mechanical recycling is the most common way to be used by almost all the plastic manufacturer. In this recycling method, shredding and grinding is generally used. The chemolysis method means the material is degraded in the effect of chemically depolymerization. This is theoretically the best recycling method for polyurethane. The thermolysis includes gasification, pyrolysis. (Biron, M. 2013, 1004)

CONCLUSION

We have attempted to indicate many aspects about polymeric composites which include the definition, classification, history, processing, testing methods and applications. Composites are mixture with different materials. Each individual acts together to form the necessary stiffness or mechanical strength. Composite have a good future because they meet various requirements. And the applications of composite related to many areas, such as aerospace, construction, sporting and marine. Nowadays, we have the enough confidence to expand the use of the new composite materials. It is possible to realize the full potential of composites after overcoming the technical, emotional and financial barriers.

However, the recycling of the composites is still a challenge. It is difficult to compete with virgin material for the recycled material because of reduction in material quality or the costs of sorting and treatment. In future, we have to face severe challenges about the recycling of the composites, such as the separation, sorting and cleaning. The driving recycling rates of composites also need to improve.

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